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GEOCHEMISTRY.—*The radium content of an ocean-bottom core.*[1] C. S. PIGGOT and W. D. URRY, Geophysical Laboratory, Carnegie Institution of Washington.

The data in the literature on the radium content of ocean-bottom sediments have been summarized by C. S. Piggot in connection with the presentation of the radium determinations made by him on 28 samples secured by the *Carnegie* on her last cruise.[2] With two or three exceptions, all the samples, including the *Carnegie* suite, were obtained from the surface of the ocean bottom or at a depth of only a few centimeters. It is obvious that a detailed radioactive study of material extending to greater depths is necessary in order to discover the mechanism by which the high concentration of radium was produced and in order to evaluate its geological significance.

The apparatus to secure core samples from the ocean bottom, developed primarily to fill this demand, has been fully described in previous publications.[3] Several cores obtained with this apparatus have been examined lithologically and chemically in detail,[4] so that they can now be sampled for radium determinations in such a manner as to facilitate the interpretation of the results.

DESCRIPTION OF THE CORE

A radium analysis of core No. 3, which was obtained by Piggot aboard the Western Union Cable Ship *Lord Kelvin* in 1936, has now been completed. The core was taken at a position roughly east of Halifax, Nova Scotia, off the Newfoundland Banks, and is 2.85 meters long.[5] It differs entirely from the rest of the suite taken across the Atlantic Ocean in exhibiting no characteristic alternating zones of sediments deposited in warm and in cold water. The volcanic shards are scarce throughout the length of the core and show little

[1] Received September 20, 1939.
[2] PIGGOT, C. S. Amer. Journ. Sci. 25: 229. 1933.
[3] PIGGOT, C. S. Bull. Geol. Soc. Amer. 47: 675. 1936; Proc. Amer. Phil. Soc. 79: 35. 1938.
[4] This examination of the Atlantic suite of cores has been carried out by the U. S. Geological Survey. U. S. Geol. Surv. Prof. Paper. (In Press.)
[5] PIGGOT, C. S. *Core samples of the Ocean-bottom and their significance.* Sci. Monthly 47: 201. 1938.

to no variation in concentration.[6] Core No. 3, in all its major aspects, is of very uniform composition both lithologically and chemically. It consists of roughly 50 percent calcium carbonate and 50 percent clay and silt and exhibits a somewhat higher clay content in three places, although the only major departure from uniformity is a thin band of silt at about 15 cm from the bottom.[7]

METHOD OF RADIUM DETERMINATION

The radium is determined by measuring the ionization current due to the disintegration of the radon in equilibrium with the radium and comparing it with the ionization current sustained by the radon from a known amount of radium. Recent developments in the technique of this method are discussed by Urry.[8] The present apparatus, which was constructed for obtaining precision, convenience, and speed in the radium determinations, with samples as small as 1 gram in weight, contains a compensating chamber system as described by Urry but differs in several important respects from the earlier apparatus. It will be fully described in a subsequent paper. The ionization current is recorded automatically by the use of a Lutz electrometer operating in the second manner of measurement previously described.[9] The laborious chemical method,[10] formerly used for obtaining the equilibrium amount of the radon—which is necessary when measuring other quantities on the same sample—has been replaced by the fusion-furnace method developed by R. D. Evans.[11] The crushed or powdered specimen is heated to about 2,000°C., thus releasing all the radon. The solid samples from the core were scraped on all sides to a depth of 1 to 3 mm and finely powdered with no separation by sieves or tabling. It is, of course, important to insure that there is no diffusion of the radon out of the specimen prior to the heating. The results in Table 1 indicate a loss of radon when the samples are left exposed to the atmosphere for 30 days after powdering. Hence the powdered core specimens were stored for this period in sealed glass tubes and the radon from the gas phase added to that obtained from the fusion of the powder. Prior to sealing, the specimens, except where otherwise stated, were heated to 600°C. in a stream of radon-free nitrogen for one hour.

[6] U. S. Geological Survey. *Op. cit.*
[7] U. S. Geological Survey. *Op. cit.*
[8] URRY, W. D. *Determination of the radium content of rocks.* Journ. Chem. Phys. 4: 40. 1936.
[9] URRY, W. D. *Op. cit.*, p. 43.
[10] URRY, W. D. *Determination of the thorium content of rocks.* Journ. Chem. Phys. 4: 34. 1936; see p. 36.
[11] EVANS, R. D. Rev. Sci. Instr. 4: 223. 1933.

RESULTS

The results in Table 1 are expressed on an air-dried basis. Judging by the 17 calcium-carbonate analyses at various depths, reduction to a carbonate-free basis would change but little the relative variations in Table 1. Nevertheless, for more complex cores it is expedient to make CO_2 and "water minus" analyses for each sample investigated, the "water minus" being determined on the actual sample taken. The present results are based on a standard radium solution prepared by the Denver Fire Clay Co., standardized by S. C. Lind and used by Piggot in former radium determinations. It is planned to base the results finally on a radium standard now in the course of preparation by the Bureau of Standards. Any change in the calibration constant of the apparatus will affect only the absolute and not the relative values given here.

TABLE 1.—THE RADIUM CONTENT OF AN OCEAN-BOTTOM CORE

Core No. 3 = P-124. Depth of water 4,700 meters.
Latitude 46°03′0″ N. Longitude 43°23′0″ W.

Specimen No.	Depth	Radium in 10^{-12} gram per gram
	cm	
P-124–0	0–2	1.21 ± .015
		(1.06 .020)**
P-124–25	25–28	1.15 .012
P-124–74*	74–77	1.24 .016
P-124–130	130–134	1.76 .026
P-124–207	207–211	1.85 .020
		(1.22 .023)**
P-124–283*	283–285	1.45 .015
P-124–268 (silt)	268–270	0.79 .008

* Somewhat higher clay content.
** Samples taken from the same powdered specimen, stored for 30 days after powdering, but not sealed.

DISCUSSION

Any discussion of these results must, at present, pertain only to this specific core. If one rightly excludes the silt result, the reason for which is given later, two points of major interest are:

A. The radium content does not diminish with depth in the core.

B. The radium content, on an air-dried basis, is close to the general run of the radium content of granites. (The average radium content of four groups of Finnish granites is *ca.* 1.6 by 10^{-12} grams Ra per gram.)[12]

Since the core apparently failed to reach the first glacial zone which

[12] PIGGOT, C. S. Amer. Journ. Sci. 35A: 227. 1938.

was reached in 29 cm at the next station, No. 4, [13] it can not very well represent a period greatly in excess of a few thousands of years. In such a short period the presence or absence of uranium I and its isotope uranium II has no measurable effect on the radium. The variation of radium with depth in the core, if there is a constant source at the surface of the ocean bottom, is controlled by ionium, which is

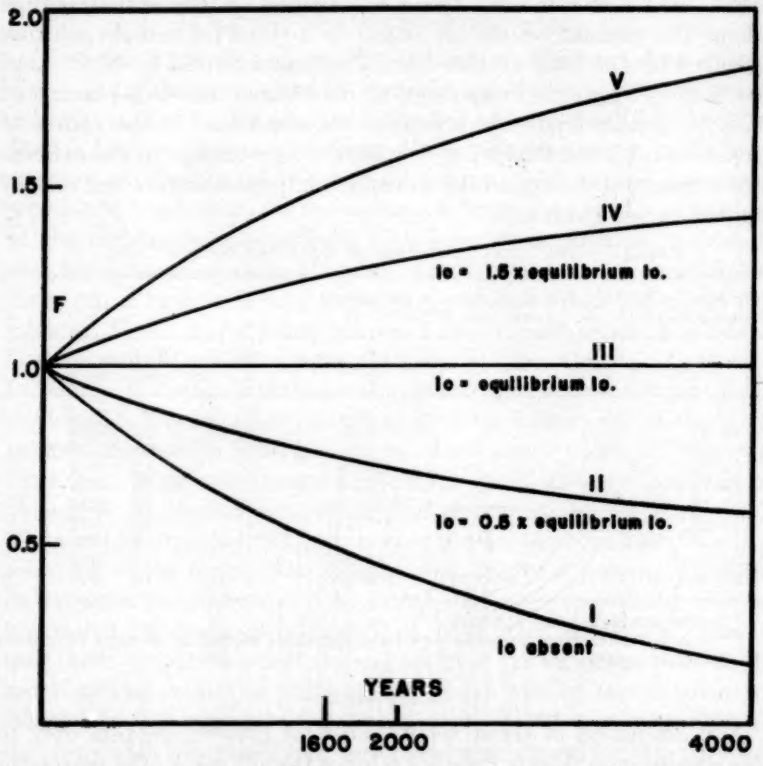

Fig. 1.—The fraction *F* of the radium content at the top of the core (surface of the ocean bottom) to be expected at a depth in the core representing a given time, under various assumptions regarding the state of radioactive equilibrium between ionium and radium.

the immediate parent of radium. Were ionium to be completely absent, the radium content would diminish with time, as shown in Fig. 1 (curve I). The 285 cm core can hardly represent less than 2,000 years, which is greater than the half life of radium (*ca.* 1,600 years). If half the equilibrium ionium amount corresponding to the radium

[13] U. S. Geological Survey. *Op. cit.*

at the surface of the bottom were present, we still would have a measurable decrease in radium with depth (curve II). If ionium and radium were deposited in equilibrium, the radium content would be constant if uranium is present (curve III) and practically constant even if uranium is absent. An excess of ionium over the equilibrium amount would yield an increasing radium content (curve IV).

A constant radium content at the present time, as is exhibited particularly in the first 77 cm of this core, would be possible even with a complete or partial absence of ionium, provided that there was a decreasing deposition of radium with time in the past following curve V or the corresponding complement of some such curve as II. Since this is entirely improbable, the original assumption of a roughly constant source of radium at the surface of the bottom is not without foundation.

Ionium, an isotope of thorium, is so different from radium in its chemical properties that a purely chemical deposition requiring approximately the amounts in radioactive equilibrium to be deposited by independent chemical processes seems unlikely in this case.

The narrow band of silt near the bottom of the core gives a result more nearly comparable with the continental sediments. There is some evidence that its origin may be due to submarine slumping.[14] It appears to be wholly foreign to the conditions of formation of the rest of the core.

In addition to a systematic examination of the radium content of the Atlantic cores, experiments are in progress to determine uranium, thorium, and ionium independently in these cores.

SUMMARY

The development of the new ocean-bottom sampler has made available a number of cores, one of the objects of the apparatus being to probe below the ocean-bottom surface and to determine the radioactive relationship between the ocean troughs and the continents.

One of the Atlantic cores is extremely uniform in composition both chemically and lithologically and was chosen as the most suitable core to examine preliminarily in order to ascertain, if possible, the radioactive equilibrium relations before proceeding to the more complex cores exhibiting wider variations in composition.

Determination of the radium content at various depths in the core shows: (A) no decrease in the radium content with depth; (B) a radium content corresponding approximately to that of the granites.

[14] U. S. Geological Survey. *Op. cit.*

The conclusions based on this exploratory investigation, which must be limited to this particular core, are: (1) that, with regard to the length of time here represented, the presence or absence of uranium has no bearing on the radium content; (2) that the ionium is probably present in an amount corresponding roughly to radioactive equilibrium with the radium; and (3) that in view of the widely different chemical properties of ionium (thorium) and radium, chemical deposition plays no role in the radioactivity of this particular core. This does not exclude the possibility that chemical deposition may be important in other instances.

PHYSICS.—*An instrument for the reproduction, regulation, and control of variable temperature.*[1,2] W. E. STONE,[3] U. S. Bureau of Entomology and Plant Quarantine. (Communicated by C. F. W. Muesebeck.)

One of the most important considerations in research on insect and other pests is the factor of temperature, especially in relation to the possibility of survival and of establishment outside the present limits of distribution. The need to determine experimentally in Mexico the possible range of distribution in the United States of the Mexican fruitfly [*Anastrepha ludens* (Loew)] and related species, as conditioned by temperature, led to the invention and development of an instrument for the laboratory reproduction of field temperatures as recorded by thermographs.

DESCRIPTION

The essential details of the construction are shown in Fig. 1. The motivating unit consists of a clock-driven cylinder *A*, *a*, of the type in general use on thermographs and mounted in the same manner on a base *b*. A temperature pattern *c* cut from fiberboard is fastened to the cylinder like a thermograph chart by a flexible metal band *d*.

The regulating unit is mounted on a vertical shaft *e*, which supports a movable stage *f*, adjustably fixed by means of a collar and setscrew. Two pairs of vertical brackets *B*, *a*, *a*, and *b*, *b*, are placed at the ends of the movable stage. Only one of each pair appears in the side ele-

[1] Received April 17, 1939.

[2] Application for public-service patent pending.

[3] The author wishes to express his appreciation to Dr. A. C. Baker, chief of the Division of Fruitfly Investigations, for helpful suggestions during the development of the instrument especially with regard to the elimination of gears to reduce play and the use of fiberboard for chart patterns; to Mr. Juan Ramirez, of the same division, for making drawings of the instrument; and to Mr. Albert J. Kramer, of the Solicitor's Office of the Department of Agriculture, from whose draft of the formal patent application much of the present description has been taken.

vational view *A*, *g* and *h*. The brackets *a*, *a* support an adjustable tracing arm *A*, *i*, fulcrumed between them on a threaded horizontal shaft by means of simple point and socket bearings. The arm is laterally adjustable on the threaded horizontal bar and adjustable in length, being composed of two parts fitted together with a slot and two setscrews. At the outer end of the tracing arm a tracing point of steel wire is attached by means of a connecting wrist and is designed to follow the contour of the chart pattern. Near the outer end the arm is slightly twisted and bent toward the cylinder so that the

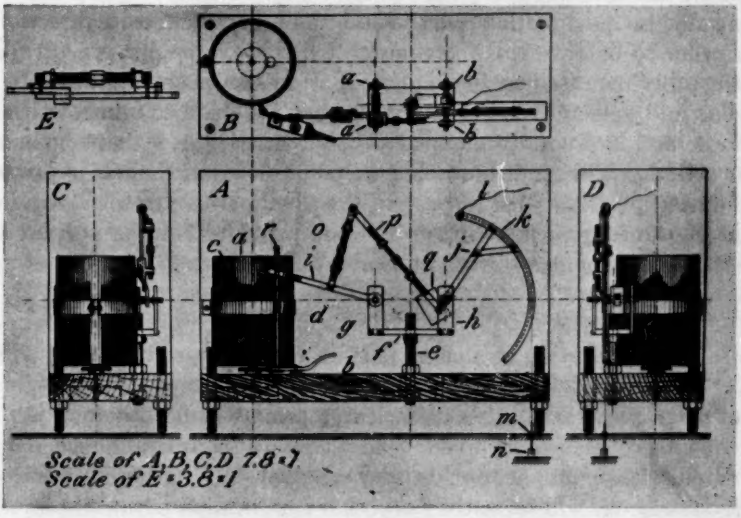

Fig. 1.—Essential details of construction of an instrument for the reproduction, regulation, and control of variable temperature: *A*, side elevational view; *B*, a plan view; *C* and *D*, end views.

tracing point, in following the contour of the temperature pattern, is not interfered with by the peaks. In a manner similar to that of the tracing arm, a lever *j* is fulcrumed between the brackets *B*, *b*, *b*. The longer arm of the lever extends upward and is joined to a segmental arc *A*, *k*, of approximately 115 degrees. At the upper end of the segmental arc a wire *l* is attached; preferably No. 37 insulated copper magneto wire should be used. The wire rests in a fine groove extending the entire length of the arc segment in the middle of its periphery. A weighted, platinum-pointed contact drop *m* is suspended from the lower end of the wire and extends to a toluene-mercury thermostat *n*. An insulator of hard composition board or other suitable insulating

material is fixed at the lower end of the drop about an inch from the point. The tracing arm and lever are mechanically linked by means of a main adjustment rod *o* and a minor adjustment rod *p*. The major adjustment rod is shown in greater detail in Fig. 1, *E*. One end of the major adjustment rod is fixed at right angles to the tracing arm at a point between its ends, the free end being pivoted to one end of the minor adjustment rod. The other end of the minor adjustment rod is pivoted to the short arm of the lever *j* substantially as shown in the drawings. Both rods are adjustable in length by means of threaded spacers set in threaded sockets. One-half of each of the spacers is threaded in one direction and the other half, in the opposite direction. In order to balance this instrument delicately, a counterweight *q* is adjustably mounted on the bearing shaft of the lever *j* by means of a collar and setscrew. A vertical guide bar *r* is fixed to a lever with a handle and is pivotally mounted at the base of the instrument near the cylinder. The guide bar holds the point of the tracer arm in proper operating position with respect to the fiberboard pattern. Threaded legs at the four corners of the base are provided for the purpose of making placement adjustments for the instrument.

PREPARATION OF CHART PATTERNS

In the preparation of a chart pattern for the reproduction of daily or weekly recorded temperatures, a heliographic copy of the original thermograph chart is made. A clearer print will be obtained if the temperature record is inked with black India ink and the chart treated with a preparation to make it translucent. Light, colorless lubricating oils will serve the purpose if standard preparations are not available. Printing with a treated chart requires approximately one-tenth of the time needed for an untreated chart. When the print is dry, it is glued or pasted on fiberboard 1 mm or slightly less in thickness with the back toward the board. The contour of the temperature record is then cut as accurately as possible with shears, and the finishing is done with an assortment of files. A graphite pencil should be run over the contour to facilitate the movement of the tracing point. The cutting of a chart pattern of a weekly temperature record requires about 20 minutes. Patterns of daily temperature records can be cut in considerably less time.

Patterns of gradually rising or falling temperatures, which are plotted in the form of a straight line or of gradually increasing or decreasing rising or falling temperature plotted in the form of a curve, may be cut quickly with a sharp knife.

In fastening the chart to the clock cylinder a better fit will be obtained if the pattern is held for a short time over a vessel of boiling water.

ADJUSTMENT AND OPERATION

After the preparation and placing of the chart pattern, the instrument is adjusted for the particular type of pattern. The initial adjustment consists in lengthening or shortening the tracing arm so that the arc described by the tracing point is of the same radius as the temperature arcs on the chart pattern. The movable stage is then raised or lowered until the arc of the tracing point, when in motion, exactly coincides with the arcs of the chart pattern at a point on the front and near the center of the pattern.

The major adjustment rod is then lengthened or shortened until the distance traversed by the contact drop, as a result of the movement of the tracer point through a given number of degrees on the pattern, is equivalent to the change in the thermostat for an equal number of degrees. The minor adjustment rod is then lengthened or shortened to rectify the position of the arc segment so that the maximum range of operation may be maintained under all adjustments.

The clock is regulated to rotate the cylinder slightly faster than the recorder to allow for the difference caused by the thickness of the fiberboard of the pattern.

When the instrument is once adjusted for a particular type of chart pattern, it will operate indefinitely without further adjustment.

In operation the tracing point rests on the top edge of the fiberboard pattern, and as the cylinder rotates it follows the contour of the pattern, raising or lowering the tracing arm. The tracing arm actuates the adjustment rods, which, in turn, actuate the arc segment. Thus the drop contact is raised or lowered in the thermostat tube, with the movement of the tracing point cutting on or off the heat by means of an ordinary electric relay connected through the thermostat and the wire extending from the upper end of the arc segment.

THERMOSTAT

A glass mercury-toluene thermostat made of 50 inches of 6/16-inch bore tubing, with an 8-inch neck of 3/16-inch bore tubing fused together and bent into a convenient form, has proved to be a good size for use with this instrument. A thermostat of this size used intermittently for 3 years has shown no apparent change in volume during that time.

When the mercury column recedes in the thermostat with a decreasing temperature, a thin film of mercury may be left on the wall of the tube for some time. As the contact drop is necessarily freehanging, the point would at times make contact with the film causing the relay to operate prematurely, except for the insulator near the end of the drop, which keeps the point away from the film.

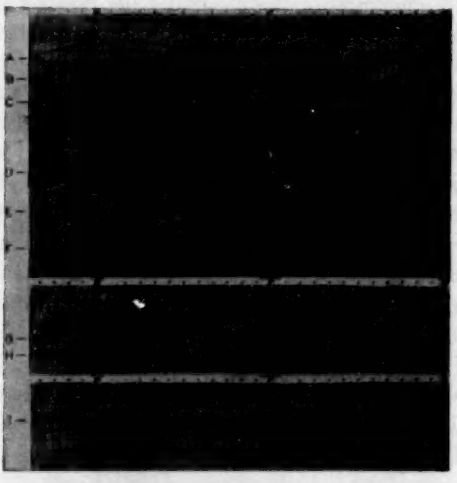

Fig. 2.—Photograph of original thermograph charts (*A*, *D*), chart patterns (*C*, *F*, *H*), records of temperature reproductions (*B*, *E*), and records of a produced gradually rising and falling temperature (*G*) and constant temperature (*I*).

There is no reason why other types of thermostats than mercury-toluene cannot be used with this instrument if they possess the necessary range.

TEMPERATURE CABINETS

Standard well-insulated temperature cabinets can not be used with this instrument when producing or reproducing highly variable temperatures unless they are equipped with cooling coils, because cooling is too slow. The need for a rapid heat exchange to obtain variable temperatures necessitates considerably larger heating elements to reach high temperatures than in constant-temperature apparatus. Air circulation must be such that the thermostat is completely enveloped in the moving air stream.

ACCURACY

The accuracy obtained in the operation of this instrument may be seen from the photograph of the charts shown in Fig. 2. *A* is an origi-

nal daily thermograph record, May 28, 1933, from Cuernavaca, State of Morelos, Mexico. *B* is a record of the reproduction of the temperature made in a cabinet at Mexico City from the chart pattern *C*. The upper part of the chart *B* has been trimmed to allow a closer comparison of the original and the reproduced temperature. An original record of a weekly temperature, June 29 to July 6, 1936, at Santa Engracia, State of Tamaulipas, Mexico, is shown in *D*. The record of the reproduced temperature, *E*, made from the chart pattern *F*, shows the accuracy with which weekly temperature records can be reproduced in the laboratory. *G* is a record of a gradually rising and falling temperature made from the chart pattern *H*. *I* is a constant-temperature record which was obtained by stopping the clock of the instrument.

SUMMARY

An instrument has been developed to permit the laboratory reproduction of field-recorded temperatures in experiments at Mexico City to determine the possible range of distribution of the Mexican fruitfly and related species in the United States. A description of the instrument showing the essential details of construction is given.

The method of preparation of the chart patterns, showing the different steps in the operation and the time consumed, and the methods of making adjustments and of operation are discussed.

A mercury-toluene thermostat made of 50 inches of 6/16-inch bore tubing with a neck of 3/16-inch bore tubing has been used with the instrument intermittently for 3 years without apparent change in volume.

Standard well-insulated temperature cabinets can not be used with the instrument when producing or reproducing highly variable temperatures unless they are equipped with cooling coils, because cooling is too slow.

The accuracy obtained in operation is shown in a photograph of charts of reproductions of daily and weekly temperature records and of the production of a gradually increasing and decreasing temperature as well as a constant temperature.

PHYSICAL CHEMISTRY.—*The assignment of uncertainties to the data of chemistry and physics, with specific recommendations for thermochemistry.*[1] FREDERICK D. ROSSINI, National Bureau of Standards, and W. EDWARDS DEMING, U. S. Department of Agriculture.

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I. INTRODUCTION

In order that the results of measurements made in different laboratories may be compared and appraised for the purpose of estimating the uncertainty or confidence interval to be attached to the published value of a physical or chemical constant, it is desirable that experimenters adopt a uniform procedure for expressing the consistency of their data, or be explicit in their statements regarding such consistency. Anyone to whom the experimental details and the original numerical data are available can form his own opinions by whatever method he likes, but since full details are often too extensive for publication, understanding among workers in different laboratories and in different countries will be promoted if all the investigators in any field will be careful to give the information that is essential for evaluating the consistencies of their final values. The purpose of this paper is to present some discussion on this subject and to offer some specific recommendations in connection with the experimental data of thermochemistry.

Precision and accuracy are terms invented for convenience in discussing errors of observation, uncertainties, and related matters. The precision of a set of observations is measured by the consistency or internal agreement reached as the series is extended under controlled conditions. Precision measures the ability of an investigator to repro-

[1] Received August 26, 1939. The numbers in brackets throughout the text indicate the references at the end of the paper.

duce his observations. If they fluctuate widely, his precision is low; but if they fluctuate within a narrower range, his precision is higher.

In contrast to precision and internal agreement, accuracy is related to the discrepancy between the mean of a set of observations and the true but "unknown" value of whatever quantity is being measured. A piece of experimentation may be at once extremely precise yet hopelessly inaccurate because of constant or systematic errors, unpredictable or even unsuspected. There are three ways of going about the problem of discovering the existence of constant or systematic errors: first, by investigating the physical principles involved in the action of the apparatus; second, by ascertaining whether there exists any unnatural trend of the final values with any one of the variables involved in the measurements; and third, by comparing the results obtained in different laboratories. Incompatible discrepancies between the results obtained by two different laboratories may convince one that constant errors are present in the work of one or both of them, but the actual recognition of the errors must be made by an investigation of the principles of the measurements. It is of course possible, by accident, for the means of two sets of experiments to be in good agreement even though one or both sets are afflicted with systematic errors. Moreover, if the number of experiments is small, the two sets of data may be in disagreement and yet free from constant errors; poor agreement merely suggests but does not prove the presence of constant errors.

In speaking of incompatible discrepancies between two sets of observations supposed to measure the same quantity, one must have in mind some measure of internal consistency for the two sets of observations and some way of comparing these internal consistencies with the difference between the means from the two sets. The important consideration is not how large the discrepancy is, but rather how the discrepancy compares in magnitude with the internal consistencies of the two sets of data. Statisticians have set up mathematical models for calculating odds against discrepancies between two means exceeding different multiples of a certain function of the measure of uncertainty of the two sets of observations, and these odds will be correct if the experiments fit the assumptions on which the calculations are based. The existence of this concordance between experiments and assumptions is difficult to ascertain in actual physical and chemical experimentation, because any one series of observations is rarely extended long enough to be compared with the mathematical model (cf. Shewhart [9]). Nevertheless, probability considerations

are helpful on the whole, and increasing use is being made of some of the simpler statistical charts and calculations.

II. SOME NOTES ON THE THEORY OF PROBABILITY

1. The single sample or set of observations

In the theory of errors, a set of n equally reliable observations is considered as a sample of n drawn at random from an indefinitely large supply (parent population) of observations that theoretically *might* be made if time and opportunity would permit. In the state of statistical control or randomness, the observations behave as if they are numbers being drawn from a hat, after thorough mixing and blindfolding. This limiting state is a goal toward which the efforts of experimentation are always directed, but the requirement for its full attainment, as judged by Shewhart's "Criterion I" [9], is much more exacting than that in the experimenter's judgment the observations have all been taken under "essentially the same conditions."

If there were no constant errors, and if randomness were attained, the mean of the parent population of observations would be the true value of the quantity being measured. The effect of a constant error is to displace the mean of the parent population above or below the true value; the correction, if ever isolated and evaluated, can be added to or subtracted from the mean of the parent population to obtain the true value.

The object of making observations is to estimate the limits within which various percentages of the next hundred or thousand observations will lie; that is, statistically, to estimate the position (value) of the mean of the parent population. Because the number taken must necessarily remain finite, the exact value of the mean of the parent population can only be approached, even in controlled experiments, where randomness exists, and one becomes increasingly interested in the probabilities associated with certain propreties of the observations that are actually made. That is to say, if $\bar{x}$ is the mean of n observations and μ is the (unknown) mean of the parent population, one might be interested in knowing the proportion of means in sets of n observations each that will differ from μ by a stated amount, or the proportion in which an interval such as $\bar{x} \pm A$ will cover μ.

In the present discussion the observations will be considered randomly drawn from a parent population that is normal (Gaussian) or nearly so. There are four reasons for this choice: First, mathematically, the normal error curve is the easiest to deal with; second, it is usually an excellent approximation when control exists; third, several

investigations on nonnormal populations have shown that even considerable departures from normality do not produce appreciable alterations in many important deductions based on the normal curve; and, fourth, it has been established that the distribution curve formed by the means of samples drawn from a nonnormal parent population is usually much more nearly normal than the population itself. While there exist several types of measurement that by nature do not have normal parent populations, deductions based on the normal law will rarely fail to be valid, provided control exists.

It is to be understood that the extreme tails or ends of the normal error curve do not represent probabilities for large errors. By the nature of the apparatus, extremely large errors may be absolutely impossible, yet the approximating normal curve attributes to these large errors a finite chance of occurrence. The normal curve is an approximation not expected to hold for large errors; it is the main portion of the curve that contributes most to the calculations: if the tails of the curve were cut off, the mathematical difficulties would be exceedingly complex, but with results, in moderate and large samples, practically not different from those obtained by the customary and simpler theory which includes the tails.

If μ denotes the mean of the parent population, then the true *error* of an observation x_i drawn therefrom will be

$$\epsilon_i = x_i - \mu. \tag{1}$$

Since μ is unknown, the error ϵ_i is also unknown. So, instead of dealing with the true but unknown errors ϵ_i, we shall find it advisable to work with the known *residuals* or *apparent errors* v_i, which are measured from the known mean $\bar{x}$ of the sample rather than from the unknown mean μ of the parent population. The definition of the residual corresponding to the observation x_i is mathematically

$$v_i = x_i - \bar{x}, \tag{2}$$

where $\bar{x}$ is the mean of the sample, defined mathematically as

$$\bar{x} = (1/n)(x_1 + x_2 + \cdots + x_n), \tag{3}$$

$x_1, x_2, \cdots, x_n$ constituting the sample of n observations.

The only difficulty in replacing μ by $\bar{x}$ and thus passing from the unknown errors (ϵ) to the known residuals (v) is that $\bar{x}$ itself fluctuates from one sample to another, and in any particular sample (set of observations) the discrepancy u between $\bar{x}$ and μ is in practice not known. This unknown error in $\bar{x}$ we shall denote by u, writing

$$u = \bar{x} - \mu. \tag{4}$$

Most of the deductions made from experimental data, by probability theory or any other method, are mainly concerned with the magnitude of u, the unknown error in the sample mean $\bar{x}$.

For laying odds concerning the error u in the mean $\bar{x}$, the most important piece of information provided by the sample is the standard deviation for single observations of the set, denoted by s and defined by

$$s^2 = (1/n)\Sigma(x_i - \bar{x})^2. \tag{5}$$

The standard deviation received its name from Karl Pearson. It is not standard in the sense of being fixed, since it fluctuates from one set of observations to another. It does, however, provide a standard measure for expressing the consistency of a set of observations, for comparing their consistency with that of another set, and for judging statistically from the results obtained at two laboratories whether constant errors are present in one or another of them.

In the usual form of probability theory, which applies when control has been attained, it is assumed that as the number of observations is increased indefinitely, the mean $\bar{x}$ approaches statistically the limit μ, and also that the standard deviation, s, approaches a limit σ, called the standard deviation of the parent population. In symbols,

$$\lim_{n\to\infty} \bar{x} = \mu \qquad \text{and} \qquad \lim_{n\to\infty} s = \sigma. \tag{6}$$

Under these conditions, the experiments are "under control." When the assumption of such limits does not lead to useful results, the probability theory in the usual form is not applicable.

The standard deviation, s, as defined in eq. 5, or any multiple thereof, possesses two important properties that make it the most desirable function to use as a measure of consistency. The first of these arises from the theorem known as Tchebycheff's inequality,[2] which has been stated in a variety of forms, one corollary being that of the n observations, $x_1, x_2, \cdots, x_n$, not more than $1/\lambda^2$ of them can be outside the interval $\bar{x} \pm \lambda s$, when $\lambda > 1$. The second is Gauss's discovery that when the observations have a normal distribution, the standard deviation, s, is more efficient for estimating σ than any other function. For example, the standard deviation is 14 percent more efficient than the average residual taken without regard to sign, and 9 percent more efficient than the mean cube of the residuals.[3] That

[2] See pp. 95–98 and elsewhere in Shewhart [3], and pp. 579–587 of Smith [4].
[3] See p. 201 of Whittaker and Robinson [5].

is to say, the standard deviation of 100 observations provides as statistically reliable an estimate of σ as the average residual, taken without regard to sign, from 114 observations; etc.

When an observer performs a number of sets of measurements of the same quantity with the same apparatus, he will find that the standard deviation fluctuates from one set of measurements to another, as has been stated. These fluctuations will occur even under the best controlled conditions. The larger the number n of observations in a given set, the smaller are the fluctuations in s. When n is large, considerable confidence may be placed in the precision of a set of experiments estimated from their standard deviation. The number of observations n enables one to judge the reliability of the estimates of the precision of the observations from their standard deviations. The number n tells how many figures are significant in recording s, a good rule being to remember that the standard deviation of s itself is about $\sigma/\sqrt{2(n-1)}$. For example, if $n=9$, $1/\sqrt{2(n-1)}=1/4$, and therefore one need record not more than two figures in s and, at that, the second figure is barely significant. More than two figures in s will hardly ever be required, though one extra figure will avoid errors of rounding off.

Various tests have been proposed by statisticians for determining the probability that a sample of n observations will reproduce the properties of the parent population within stated limits, that is to say, how well the mean $\bar{x}$ and the standard deviation, s, of a finite number of observations n will represent the mean μ and the standard deviation σ that would be obtained by continuing the measurements indefinitely. Also, calculations have been made for evaluating the odds on the occurrence of given differences between the means of two sets of observations.

The normal curve showing the distribution of the mean values of samples or sets of n observations has for its standard deviation $\sigma/\sqrt{n}$, which is smaller than σ because of the denominator $\sqrt{n}$. This quantity $\sigma/\sqrt{n}$ can be used to compute the probability that expresses the chance P_τ of the occurrence of an error u in $\bar{x}$ greater than some stated amount, say E. The graph in Fig. 1 shows P_τ as a function of τ, where

$$\tau = E/(\sigma/\sqrt{n}). \tag{7}$$

This quantity τ is the "standardized error," or the stated error E expressed in units of the standard deviation of the error u in $\bar{x}$. In the long run of repeated sampling under controlled conditions the stand-

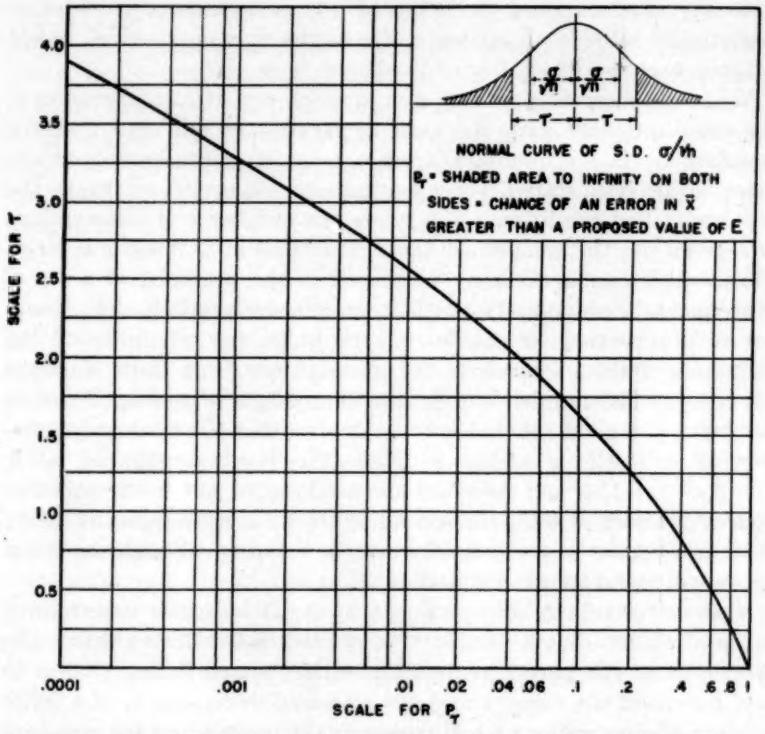

Fig. 1.—Areas under the normal curve. P_τ is the area in both tails beyond the abscissas $\pm\tau$. The whole area under the curve is unity, i. e. $P_\tau = 1$ when $\tau = 0$.

ard deviation of the error u is $\sigma/\sqrt{n}$, as has already been mentioned, and P_τ is the fractional number of times that the error u in $\bar{x}$ will in the long run exceed the stated error E. The calculation of τ and the corresponding P_τ is called the normal test for the significance of $\bar{x}$.

Reliable estimates of σ for the normal test can sometimes be made antecedently from a long series of previous observations, or from several short series,[4] and it is to be noted that in the absence of a reliable estimate of σ, one can not compute τ and hence can not look up P_τ in the tables. The best one can do in such circumstances is to use the Student "t" test [1, 6], which involves the fluctuating standard deviation, s, of the single sample, in place of the steady (but now supposedly unknown) σ. The "t" test is made by estimating σ from the one sample according to the formula

[4] See Deming and Birge [1], eq. 67, p. 158.

$$s' = s\sqrt{n/(n-1)} = \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{n-1}}, \tag{8}$$

and then measuring E in terms of $s'/\sqrt{n}$, calling the result t. Now if s' is an estimate of σ, then $s'/\sqrt{n}$ is an estimate of $\sigma/\sqrt{n}$, wherefore, if we write

$$t = E/(s'/\sqrt{n}) = E \div \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{n(n-1)}}, \tag{9}$$

we may look upon t as an estimate of τ, the only distinction being that τ in eq. 7 is the stated error E measured in units of $\sigma/\sqrt{n}$, whereas t in eq. 9 is measured in units of an *estimate* of $\sigma/\sqrt{n}$. In words, t is the stated error E measured in units of the estimated standard deviation of the error u in $\bar{x}$. Otherwise written, we may say that

$$t = (E/s)\sqrt{k}, \tag{9a}$$

wherein $k = n - 1$, and s is computed according to eq. 5. In place of the probabilities P_τ in terms of τ in Fig. 1, we now have the probabilities P_t in terms of t and k in Nekrassoff's nomograph shown as Fig. 2. P_τ is to be used when σ is known; P_t when σ is not known.

It is to be kept in mind that P_τ, when we are able to calculate it, may be found different from P_t; in fact, the two will agree only when the observed s happens to be an "average" s. If s is unusually high or low, as it will be once in a while, then P_t will be correspondingly low or high compared with P_τ. It is to be remembered also that neither the normal test nor the "t" test is valid except in statistical control, and by the time this state is attained the experimenter usually knows his σ and has no need of the "t" test.[5] In statistical control, as n increases indefinitely, s' approaches σ, t approaches τ, and P_t approaches P_τ.

2. A pair of samples or sets of observations

The following information will be available from the recorded data of the two sets of observations:

	1st set	*2d set*
Mean	$\bar{x}_1$	$\bar{x}_2$
Standard deviation	s_1	s_2
Number of observations	n_1	n_2

In examining the concordance of two sets of measurements sup-

[5] For some critical remarks, see the 1937 and 1938 editions of Deming and Birge [1], especially the "additional notes" and pp. 131–139.

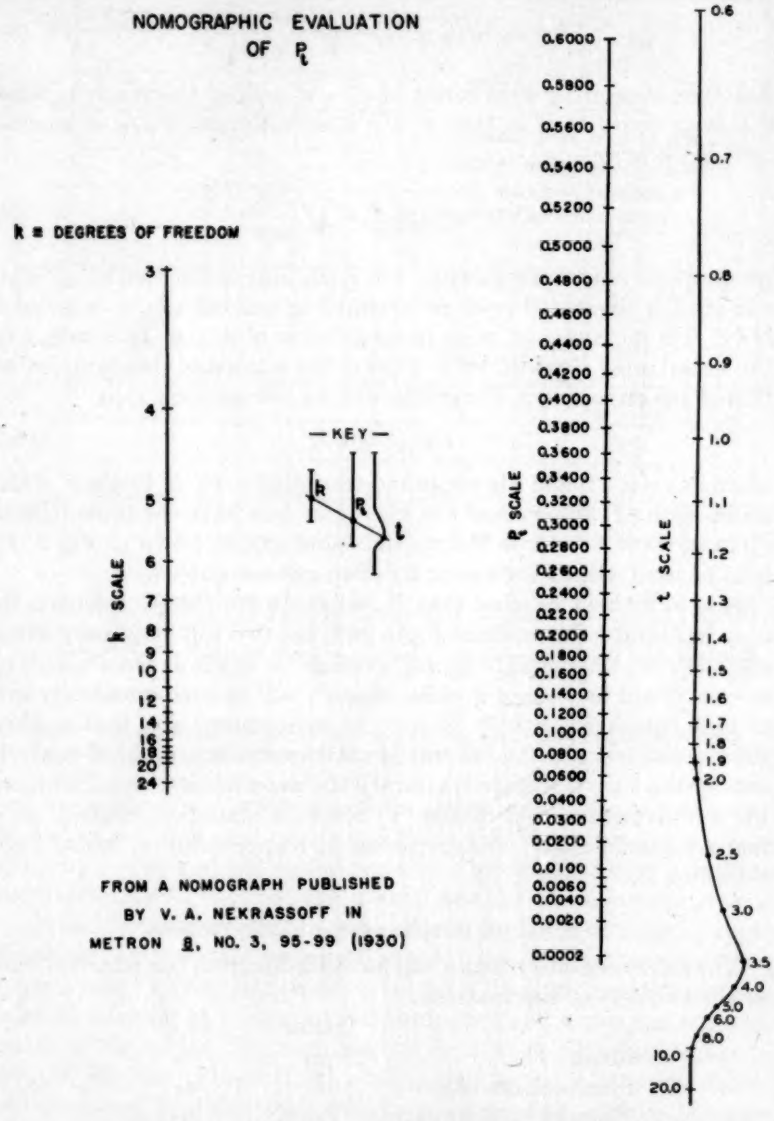

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Fig. 2.—Nomographic evaluation of P_t.

posedly made on the same magnitude, the important fact to keep in mind is that if both sets are under control, then, in repeated sampling, the difference $\bar{x}_1 - \bar{x}_2$ between the two means will be distributed normally about 0 with standard deviation $(\sigma_1^2/n_1 + \sigma_2^2/n_2)^{1/2}$, σ_1 and σ_2 being the precisions of single observations in the two samples. To discover the probability of a difference as great as or greater than that actually observed, we need only calculate

$$\tau = |\bar{x}_1 - \bar{x}_2| / (\sigma_1^2/n_1 + \sigma_2^2/n_2)^{1/2}, \tag{10}$$

and then look up P_τ in Fig. 1 or in any table of the normal integral.

In the case of the single sample we ran into the difficulty that σ is sometimes unknown, and we were forced to the "t" test. So it is with a pair of samples also; when σ_1 and σ_2 are both unknown, we can not compute τ in eq. 10 and hence can not look up P_τ. But if, as frequently happens, it can be asserted that σ_1 and σ_2 have a common value, say σ, then we may apply the "t" test by calculating

$$t = |\bar{x}_1 - \bar{x}_2| / s' \left(\frac{1}{n_1} + \frac{1}{n_2}\right)^{1/2}, \tag{11}$$

with

$$s'^2 = \frac{n_1 s_1^2 + n_2 s_2^2}{n_1 + n_2 - 2}, \tag{12}$$

and then looking up P_t on Nekrassoff's nomograph (Fig. 2) with $k = n_1 + n_2 - 2$. It is to be noted that s' is an estimate of σ obtained by pooling both samples, and that t as defined in eq. 11 is the difference $|\bar{x}_1 - \bar{x}_2|$ divided by $s'(1/n_1 + 1/n_2)^{1/2}$, which is the estimated standard deviation of the sampling fluctuation of $\bar{x}_1 - \bar{x}_2$. We may therefore look upon t in eq. 11 as an estimate of the τ in eq. 10, the relation between them being similar to that between the t and τ of eqs. 9 and 7.

In the state of statistical control, P_t represents the relative frequency of occurrence, in the long run, of values of t as large as or larger than that calculated in eq. 11, the presumption being that both sets of observations were made on the same thing, i. e., that both sets were afflicted with the same constant errors. A large value of t, giving a low value of P_t, is an indication that the two means $\bar{x}_1$ and $\bar{x}_2$ are unduly discordant compared with their internal consistencies as measured by s_1 and s_2. Since unequal constant errors in the two experiments would separate $\bar{x}_1$ and $\bar{x}_2$, on the average, leaving s_1 and s_2 and s' unaffected, we may regard a low value of P_t as statistical

"evidence" of unequal constant errors. A low value of P_t, e. g., 0.01, is of course no proof of the existence of constant errors, but rather an indication that an investigation into the possibility should be made. On the other hand, a high value of P_t is no assurance that constant errors are absent or operating equally. One can only assert that an unequal distribution of constant errors causes low values of P_t to occur more frequently than would happen by chance under ideal conditions.

When, because of unavoidable circumstances, the numerical data of a given investigation can not be published in complete detail, the procedure of estimating and reporting the measure of the precision should preserve as much as possible of the information contained in the full series of observations. In those cases where complete publication is not possible, condensation of the numerical data becomes necessary, and the investigator should report at least the three following pieces of information

(i) The number of observations, n.

(ii) The mean $\bar{x}$ of the observed values, calculated to as many figures as are judged significant in consideration of the standard deviation.

(iii) The standard deviation, s, given to as many figures as are judged significant in consideration of the number of observations.

The number of significant figures to which the mean value $\bar{x}$ is reported should be dictated by the internal consistency of the observations, that is, by the magnitude of the standard deviation, and not by what one may consider to be the accuracy of the experiments. If one or more decimals are dropped from a mean, it may be impossible to correct it to a more accurate value later on when one or more constant errors may be traced and evaluated. Furthermore, a comparison of the discrepancy between two means with the internal consistencies of the two sets of observations is hardly possible unless each mean is carried out to as many significant figures as are warranted by the standard deviation.

3. Functional concordance

Hitherto the n measurements were all supposed to have been made on a single magnitude. Quite commonly, however, one has to deal with a more complicated case of curve fitting; some measurements may be here, and others there, as happens for example when a vapor pressure is observed as a function of the temperature. As the temperature changes, so does the vapor pressure, and one may wish to ob-

serve the vapor pressure at several different temperatures, and afterward fit a curve to the observed points. Sometimes only one measurement is taken on y for a given x, or on x for a given y, but it is highly desirable that repeated observations be made whenever possible, in order to see how well the curve fits (see, for example, pp. 20–25 of Deming's *Least Squares* [12]). Sometimes only y is subject to error; but more generally x and y may both be in error, in which case the problem of adjustment is still easily taken care of (cf. Deming [12],

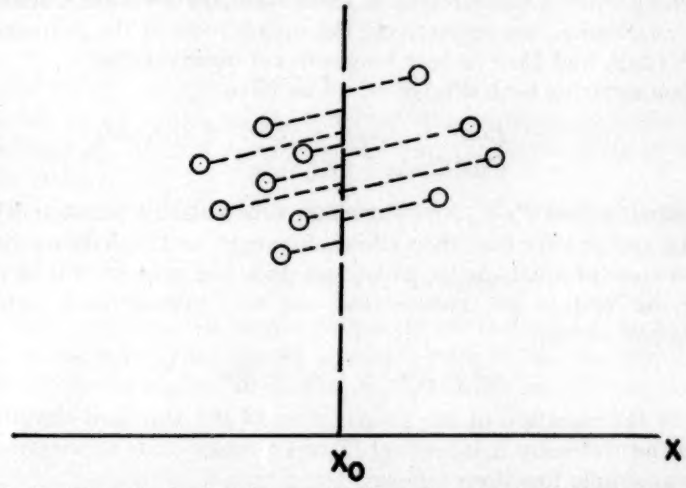


Fig. 3.—Here y is observed for several values of x, none of which is far from x_0. If one knows the slope dy/dx of the functional relation between x and y at x_0, or knows the shape of the relation in that vicinity, he can easily project the observations to find the concordance at x_0, i. e., to find what might have been obtained if x had been held at x_0.

pp. 82 and 83 ff). In any event, when the curve has been fitted, an estimate of the precisions of the observations on y and x can be made.

Occasionally, y is observed for several values of x within a range close of x_0. One can then, in effect, move the points graphically to the abscissa x_0 as shown in Fig. 3. The standard deviation of y at x_0 can easily be computed by taking the root mean square deviation of y from its mean value at x_0 according to eq. 5.

III. PROPAGATION AND COMBINATION OF ERRORS

If the quantity F is a function of x, y, and z, and these are in error by the amounts Δx, Δy, and Δz, respectively, then F will be in error by an amount ΔF whose value is given approximately by the linear terms of a Taylor's series:

$$\Delta F = F_x\Delta x + F_y\Delta y + F_z\Delta z + \cdots. \tag{13}$$

Here the higher powers and products of Δx, Δy, and Δz have been neglected, since it is assumed that the errors are small. (F_x, F_y, and F_z stand for dF/dx, dF/dy, and dF/dz, respectively, and each derivative is to be evaluated at or near the correct values of x, y, and z.) Eq. 13 is the equation of propagation of error.

In practice, one does not know the individual errors in x, y, and z, but may have some knowledge regarding their standard deviations from long series of measurements. These standard deviations, denoted by σ_x, σ_y, and σ_z, are respectively the square roots of the averages of $(\Delta x)^2$, $(\Delta y)^2$, and $(\Delta z)^2$ in very long series of observations.

Upon squaring both sides of eq. 13 we have

$$\begin{aligned}(\Delta F)^2 = {} & (F_x\Delta x)^2 + (F_y\Delta y)^2 + (F_z\Delta z)^2 + 2F_xF_y\Delta x\Delta y \\ & + 2F_xF_z\Delta x\Delta z + 2F_yF_z\Delta y\Delta z.\end{aligned} \tag{14}$$

Assuming that F_x, F_y, and F_z remain substantially constant while Δx, Δy, and Δz vary over their allowable ranges, and that the averages of the cross products $\Delta x\Delta y$, $\Delta x\Delta z$, and $\Delta y\Delta z$ are zero, as will be true if Δx, Δy, and Δz are uncorrelated, one may average each term of eq. 14 and obtain

$$\sigma_F^2 = F_x^2\sigma_x^2 + F_y^2\sigma_y^2 + F_z^2\sigma_z^2. \tag{15}$$

This is the equation of the propagation of the standard deviation, when the errors are independent. Two examples of its application to various simple functions follow.

(i) If

$$F = ax + by + cz, \tag{16}$$

where the errors in x, y, and z are independent of one another, then the standard deviation of F, resulting from the errors in x, y, and z, is given by the relation

$$\sigma_F = \{(a\sigma_x)^2 + (b\sigma_y)^2 + (c\sigma_z)^2\}^{1/2}. \tag{17}$$

Here σ_x, σ_y, and σ_z are the standard deviations of the errors in x, y, and z. It is to be noted that this formula remains unaltered if a, b, or c changes sign.

(ii) If

$$F = x^\alpha y^\beta z^\gamma, \tag{18}$$

where the errors in x, y, and z are independent of one another, then the resulting standard deviation of F is

$$\sigma_F = F\{(\alpha\sigma_x/x)^2 + (\beta\sigma_y/y)^2 + (\gamma\sigma_z/z)^2\}^{1/2}. \tag{19}$$

This formula remains unaltered if α, β, or γ changes sign.

Separately obtained mean values, if within reasonable accord with one another, may be combined by weighting them inversely as the squares of their standard deviations. (Just whether two sets of observations are in accord with one another is a matter that can not be decided objectively, but the normal test or the "t" test will at times be of assistance.) If, for example, three sets of measurements of a certain quantity yield the three means $\bar{x}_1$, $\bar{x}_2$, and $\bar{x}_3$, the resulting weighted mean will be

$$\bar{x} = \frac{n_1\bar{x}_1/\sigma_1^2 + n_2\bar{x}_2/\sigma_2^2 + n_3\bar{x}_3/\sigma_3^2}{n_1/\sigma_1^2 + n_2/\sigma_2^2 + n_3/\sigma_3^2}, \tag{20}$$

wherein n_1, n_2, and n_3 are the numbers of measurements in the three sets, and σ_1, σ_2, and σ_3 express the standard deviations of single observations.

The standard deviation to be assigned to the resulting weighted mean $\bar{x}$ will be

$$\sigma_{\bar{x}} = 1/(n_1/\sigma_1^2 + n_2/\sigma_2^2 + n_3/\sigma_3^2)^{1/2}. \tag{21}$$

The bar over the σ is a reminder that the character refers to a mean.

If in the same symbolism $\bar{\sigma}_1$, $\bar{\sigma}_2$, and $\bar{\sigma}_3$ refer to the standard deviations of the three separate means $\bar{x}_1$, $\bar{x}_2$, and $\bar{x}_3$, eqs. 20 and 21 take the forms

$$\bar{x} = \frac{\bar{x}_1/\bar{\sigma}_1^2 + \bar{x}_2/\bar{\sigma}_2^2 + \bar{x}_3/\bar{\sigma}_3^2}{1/\bar{\sigma}_1^2 + 1/\bar{\sigma}_2^2 + 1/\bar{\sigma}_3^2}, \tag{22}$$

$$\bar{\sigma}_{\bar{x}} = 1/(1/\bar{\sigma}_1^2 + 1/\bar{\sigma}_2^2 + 1/\bar{\sigma}_3^2)^{1/2}. \tag{23}$$

These formulas are easily extended to any number of sets of observations.

IV. APPLICATION TO MEASUREMENTS IN GENERAL

The calculations outlined on the preceding pages may be applied to any experiment that is in statistical control; i. e., when the data are known to be random.[6] Possible examples that can be developed in general physical and chemical measurements are the determinations of heats of chemical reactions, heat capacities, heats of fusion and vaporization, freezing and boiling points, volumes, molecular weights, densities, refractive indices, solubilities, and various chemical analyses.

Physical and chemical measurements may be divided roughly into

[6] See, in particular, chapter II of Shewhart [9].

two classes, of which the second is further subdivided into two parts:[7]

A. Absolute or primary measurements.

B. Comparative or secondary measurements.

a. By successive comparison.

b. By simultaneous comparison.

In physicochemical measurements, the investigator must carefully distinguish between the precision and the accuracy of his results, and, furthermore, he must establish beyond reasonable doubt that the purity of the chemical substances upon which the measurements are being made is sufficient for the purposes of the investigation. Methods for establishing the purity of chemical substances have been discussed in detail by a number of authors (for example, see Washburn [8]).

There are relatively few investigations that in themselves completely determine the final value of a desired property. Usually the final value is a function of a number of quantities, only one of which will be evaluated in the investigation, the others being "accepted" from other sources. For example, the final value Q may be a function of the quantities A, B, and C, of which C is the only one that is evaluated in the investigation: thus, it might be that

$$Q = ABC. \tag{24}$$

The precision of the measurements on C is a measure of the precision of C but not of Q. The precision of $C(=Q/AB)$ may be considered the "immediate" precision of the measurements, and this is to be contrasted with the "overall" precision of Q, which must include the precisions of A and B as well as of C. The standard deviation to be assigned to A and B should be estimated, in a manner similar to that used in estimating the standard deviation of C, from measurements made in the laboratories where A and B were determined. When no systematic errors exist in A or B or C, then the "overall" standard deviation, estimated by the propagation of the standard deviations of the various component parts, gives an idea of the accuracy of the experiment. It is only through the concordance of different methods of measurement that a measurable characteristic is ever said to have an existence that is operationally verifiable; but no matter how close this concordance appears to be, there is always the possibility that future experimental or theoretical work may reveal the presence of constant errors, whereupon our ideas concerning the accuracy of a

[7] For further definition and discussion of absolute and relative measurements, see Swietoslawski [7].

measured quantity will need to be revised (cf. Shewhart [9], chapter IV).

Absolute or primary measurements are those in which the resulting magnitude is measured in terms of fundamental or absolute standards. Examples of this class include the determination of the density of water in terms of the fundamental units of mass and volume; the heat of formation of water in terms of the fundamental unit of energy; and the absolute viscosity of water in terms of fundamental units. For such measurements the finally determined value of Q will be the resultant of sets of measurements on one or more magnitudes. The standard deviation of the magnitude resulting from each of the component sets of observations may be estimated according to the procedure discussed in Section II, these separate standard deviations then being combined by the procedure given in Section III for the propagation of errors. Strictly, the formulas developed there are valid only for the true values of the standard deviations involved, but they will be sufficiently close for the purpose when used with estimated standard deviations.

Comparative or secondary measurements are those in which the resulting magnitude is determined by comparison with a selected standard or reference substance, in terms of a "best" value more or less arbitrarily assigned or accepted for the standard. For such measurements, it is to be emphasized that the evaluation of the "overall" standard deviation of the resulting value entails a consideration not only of the errors in the immediate experiment, but also of the uncertainty in the value selected for the standard substance in terms of the fundamental units. This latter uncertainty must be inferred from absolute or primary measurements made in a laboratory adequately equipped to determine the value for the standard substance in terms of the fundamental units.

Secondary measurements involving successive comparison with the standard or reference substance include, for example, the determination of the viscosity of a liquid with a viscosimeter standardized with water (using an "accepted" value for the latter) and the determination of the heat of combustion of an organic substance with a bomb calorimetric apparatus standardized with benzoic acid. In such measurements, the final value Q is the resultant of two sets of measurements with the same apparatus under as nearly the same conditions as possible. In one set the reference substance is measured, and in the other the experimental substance. This type of measurement determines the ratio of the property for the one to that for the other,

as for example, Q_w/Q_r. If the estimated standard deviations (Section II) are respectively σ_w and σ_r, then for Q_w/Q_r, which measures Q_w in terms of the units and value accepted for the standard, the resulting standard deviation is that obtained by combining σ_w and σ_r in a manner indicated in Section III. It should be noted that this result takes no account of the uncertainty in the value selected for the standard substance.

Secondary measurements involving simultaneous comparisons of the given substance with the standard or reference, include, for example, the determination of relative heat capacities with "twin" calorimeters, of relative P-V-T data with "twin" bombs, and of relative densities with "twin" pycnometers. In such measurements, the final value Q is usually the result of measurements with a "twin" apparatus containing both the given substance and the reference or standard. This type of measurement substantially determines the difference between the value of the property for the experimental substance and that for the reference substance, as for example, $Q_w - Q_r$. In practice the reference substance is selected to make the observed difference $Q_w - Q_r$ small in comparison with Q_r. The resulting standard deviation for the value of Q_w, expressed in terms of the units and value adopted for the reference substance, will be simply the standard deviation for the value $Q_w - Q_r$, evaluated from the data according to the procedure given in Sections II and III. This standard deviation likewise takes no account of the uncertainty in the value selected for the reference substance.

V. SPECIFIC RECOMMENDATIONS FOR THERMOCHEMISTRY

1. General remarks

In thermochemical investigations, systematic errors may arise from a number of sources, including the evaluation of the energy equivalent of the calorimeter, the determination of the amount of reaction, etc.[8] Such systematic errors, which affect the accuracy but usually not the precision of the results, may preclude agreement among different laboratories as to the results of measuring what is supposedly the same thing, even though the consistency of the measurements in each of the laboratories by itself is entirely satisfactory.

The standard deviations associated with the "accepted" constants and other constant factors entering into the reduction of the data should be incorporated, so far as they are significant, into the final "overall" standard deviation assigned to the quantity being evalu-

[8] For a detailed discussion of such factors, see reference [10].

ated. In the report of an investigation, such constants and their assigned standard deviations should be identified and the reasons for their selection given.

The standard deviation that is to be associated with the mean $\bar{x}$ of a set of n observations in a state of statistical control is $1/\sqrt{n}$ times the standard deviation (for single observations) of the parent population from which the observations are drawn (see Section II). An estimate $\bar{s}'$ of the standard deviation of $\bar{x}$ can therefore be obtained by multiplying s' in eq. 8 by $1/\sqrt{n}$, whence

$$\bar{s}' = s'/\sqrt{n} = \sqrt{\Sigma v_i^2/n(n-1)}, \tag{25}$$

where Σv_i^2 is the sum of the squares of the deviations, each deviation being measured from $\bar{x}$, that is, $v_i = x_i - \bar{x}$, as in eq. 2. (It will be recalled that s' is the estimated standard deviation for single observations of a given set, and that $\bar{s}'$ is the estimated standard deviation of the mean $\bar{x}$.)

It is again emphasized that the procedure described here for treating the observations of experimental thermochemistry statistically is applicable only if the observations are in a state of statistical control (see Section II).

2. Procedure for combining standard deviations

Following the general classification already given in Section IV, calorimetric investigations of the heats of chemical reactions may be divided into those involving (A) absolute or primary measurements and (B) comparative or secondary measurements.

A. Absolute or primary measurements

In thermochemical investigations involving absolute or primary measurements, the heat evolved by a measured amount of chemical reaction is compared with the heat evolved by a measured amount of electrical energy, using the calorimeter system as the absorber and comparator of the two kinds of energies. In the ideal case, both a fixed calorimeter system and a fixed temperature rise would be used, so that a direct equality would be obtained between a measured amount of electrical energy and a measured amount of chemical reaction [10].

In actual practice it is easy to use a fixed calorimeter system but impracticable to try to obtain exactly the same temperature rise in all experiments. Instead, with the fixed calorimeter system, the temperature rise is made substantially the same in all experiments, and

the small differences from one experiment to another are measured in order to effect the correction to a common temperature rise. In most cases the amount of electrical or chemical energy added to the calorimeter can be so regulated that the differences in the temperature changes in the various experiments will differ from zero by at most several percent of the total change. Since the small differences can be measured as precisely as necessary, the advantage of the substitutional nature of the method is retained, and the experimenter gains some needed flexibility in operation.

For the given calorimeter system, it is convenient to determine a quantity called its energy equivalent.[9] This quantity A is the amount of electrical energy E added to the fixed calorimeter system divided by the temperature rise Δt_E, the amount of energy added being regulated so that Δt_E differs little from the selected "standard" temperature rise. The relation used in computing the energy equivalent of the calorimeter is

$$A/f = E/\Delta t_E, \tag{26}$$

where E is the observed electrical energy, Δt_E is the observed temperature rise, A is the energy equivalent of the calorimeter, and f is a constant whose value is the resultant of the various calibration factors associated with the instruments used in measuring the electrical energy, such as the standard resistances, standard cell, resistance coils of the potentiometer, timing apparatus, etc. The product fE gives the electrical energy in terms of fundamental units. In the experiments with electrical energy, the quantities actually observed are E and Δt_E, and for each experiment there is determined a value of the ratio $E/\Delta t_E$. From a series of η such determinations of $E/\Delta t_E$, there is obtained an average value of $E/\Delta t_E$, this average being the experimental determination of A/f according to eq. 26. By applying eq. 25 to the measurements of $E/\Delta t_E$ one may calculate

$$s'_{A/f} = \sqrt{\Sigma v_i^2/n(n-1)} \tag{27}$$

as an estimate of the standard deviation to be assigned to the determination of A/f.

[9] This quantity is substantially the same as that which has been called by many writers the heat capacity of the calorimeter, but the latter designation is not recommended because it implies that the investigator has a knowledge of the actual physical boundaries of the material system to which the heat capacity is ascribed, and that the heat capacity of the calorimeter may be evaluated by a summation of the heat capacities of its component parts. As has already been pointed out [10], this latter procedure is not admissible in modern thermochemical investigations.

In a series of calorimetric reaction experiments, there is measured the amount of chemical reaction that produces, in the calorimeter, a temperature rise substantially equal to the selected "standard" temperature rise. The relation used in reducing the data of these experiments is

$$Bg = \Delta t_R / W_R, \tag{28}$$

where Δt_R is the observed temperature rise, W_R is the observed mass of the substance (either reactant or product) that is used to determine the amount of reaction, B is the temperature rise per unit mass of the selected substance that determines the amount of reaction, and g is a factor whose value is the resultant of the various factors required to convert the observed mass of the selected substance to the number of moles of the desired pure reaction, which conversion involves the molecular weight of the selected substance, a correction for any impurity in the reaction, etc. In the experiments with chemical energy, the quantities actually observed are Δt_R and W_R, and for each experiment there is determined a value of the ratio $\Delta t_R/W_R$. From a series of n such determinations of $\Delta t_R/W_R$, there is obtained an average value of $\Delta t_R/W_R$, this average being the experimental determination of Bg according to eq. 28. By applying eq. 25 to the measurements of $\Delta t_R/W_R$ one calculates

$$s'_{Bg} = \sqrt{\Sigma v_i^2/n(n-1)} \tag{29}$$

as an estimate of the standard deviation to be assigned to the determination of Bg.

The experimental value of the heat Q of one mole of the reaction being studied is obtained from the relation

$$Q = AB, \tag{30}$$

which can be written

$$Q = (E/\Delta t_E)(\Delta t_R/W_R)f/g. \tag{31}$$

The ratios $E/\Delta t_E$ and $\Delta t_R/W_R$ are evaluated in the electrical energy and the chemical reaction experiments, respectively, and the ratio f/g includes all the constant factors involved in the reduction of the data. In the experiments, Δt_E and Δt_R are made as nearly alike as possible, and since these temperature rises occur in eq. 31 only as the ratio $\Delta t_R/\Delta t_E$, the thermometer need not be calibrated in an absolute sense. In fact, the substitutional nature of the experiments can be further emphasized by reporting the values of Δt_E and Δt_R

in the units in which they are actually measured (microvolts if the thermometric device is a thermoelement and ohms if it is a resistance thermometer) without conversion to degrees on the temperature scale.

By an appropriate analysis of the information supplied by the standardizing and other laboratories, the investigator may be able to estimate the magnitude of the standard deviations associated with the constant factors f and g used in reducing the data. If these estimates are denoted by $\bar{s}'_f$ and $\bar{s}'_g$, then, by comparing eqs. 18 and 31 and applying eq. 19, the final "overall" standard deviation to be assigned to the experimental value of Q is found to be

$$\bar{s}'_Q = Q\sqrt{[\bar{s}'_{A/f}/(A/f)]^2 + [\bar{s}'_{Bg}/Bg]^2 + [\bar{s}'_f/f]^2 + [\bar{s}'_g/g]^2}. \qquad (32)$$

The value of $\bar{s}'_Q$ given by eq. 32 is seen to be derived from a combination of four terms, the first from the experiments with electrical energy, the second from the experiments with chemical energy, and the third and fourth from the constant factors used in reducing the data. In the actual practice of thermochemical investigations, the uncertainties in the calibration factors to be applied to the nominal values of the standard resistances, standard cells, etc., are nearly always negligible, or can be made so by appropriate calibration at the national standardizing laboratory. Likewise, the correction for an impurity in the reaction, if any is present, can usually be made with negligible uncertainty by application of the appropriate analytical technic in the chemical analysis of the reaction [10]. It appears, therefore, that by adequate calibration and chemical techniques, the uncertainties in the factors f and g in eq. 31 can usually be made negligible in comparison with those of A/f and Bg. Under such circumstances the last two terms under the radical in eq. 32 may be neglected, and the final "overall" standard deviation to be assigned to the experimental value of Q becomes simply

$$\bar{s}'_Q = Q\sqrt{[\bar{s}'_{A/f}/(A/f)]^2 + [\bar{s}'_{Bg}/Bg]^2}. \qquad (33)$$

B. Comparative or secondary measurements

In thermochemical investigations comparative or secondary measurements have so far been made only by successive comparison. In such experiments the heat evolved by a measured amount of the given chemical reaction is compared with the heat evolved by a measured amount of a selected "standard" or reference reaction, using a fixed calorimeter system with a substantially constant tem-

perature rise. The heat evolved per unit amount of the selected reference reaction, which is chemically similar to the one being investigated, has been determined, in terms of fundamental units for the reaction occurring under certain standard conditions, in an appropriate standardizing laboratory. These comparative or secondary thermochemical measurements are the same as the absolute or primary ones except that the energy equivalent of the calorimeter is determined not with electrical energy but with the heat evolved by a measured amount of the standard or reference reaction taken under "standard" conditions.

The relation used in computing the energy equivalent of the calorimeter from the data of the experiments with the reference reaction

$$C/D = W_s/\Delta t_s, \tag{34}$$

is where W_s is the observed mass of that reactant or product of the standardizing reaction which is used to determine the amount of reaction, Δt_s is the observed temperature rise, C is the energy equivalent of the calorimeter in terms of the value and units assigned to the standardizing reaction, and D is the value assigned to the standardizing reaction for the heat evolved per unit mass of the reactant or product that determines the amount of reaction when the reaction occurs under the conditions maintained in the experiments in the standardizing laboratory. In the experiments with the reference reaction, the quantities actually observed are W_s and Δt_s, and for each experiment there is determined a value of the ratio $W_s/\Delta t_s$. From a series of n such determinations of $W_s/\Delta t_s$, there is obtained an average value of $W_s/\Delta t_s$, this average being the experimental determination of C/D according to eq. 34. By applying eq. 25 to the measurements of $W_s/\Delta t_s$, one may calculate

$$s'_{C/D} = \sqrt{\Sigma v_i^2/n(n-1)} \tag{35}$$

as an estimate of the standard deviation to be assigned to the determination of C/D.

In a series of calorimetric reaction experiments, the reaction whose heat is to be determined is carried out under conditions substantially identical to those maintained in the experiments with the standardizing reaction. The relation used in reducing the data of these experiments is

$$Bg = \Delta t_R/W_R, \tag{36}$$

where Δt_R is the observed temperature rise, W_R is the observed mass

of the reactant or product of the given reaction that is used to determine the amount of reaction, B is the temperature rise per unit mass of the selected substance that determines the amount of reaction, and g has the same significance as in eq. 28. In these experiments, the quantities actually observed are Δt_R and W_R, and for each experiment there is determined a value of the ratio $\Delta t_R/W_R$. From a series of n such determinations of $\Delta t_R/W_R$, there is obtained an average value of $\Delta t_R/W_R$, this average being the experimental determination of Bg according to eq. 36. By applying eq. 25 to the measurements of $\Delta t_R/W_R$ one may calculate

$$\bar{s}'_{Bg} = \sqrt{\Sigma v_i^2/n(n-1)} \tag{37}$$

as an estimate of the standard deviation to be assigned to the determination of Bg.

The experimental value of the heat Q of one mole of the reaction under investigation is obtained from the relation

$$Q = CB, \tag{38}$$

which can be written

$$Q = (W_s/\Delta t_s)(\Delta t_R/W_R)D/g. \tag{39}$$

The ratios $W_s/\Delta t_s$ and $\Delta t_R/W_R$ are measured in the two series of calorimetric reaction experiments, the first with the standardizing reaction and the second with the reaction whose heat is to be determined. The ratio D/g contains all the constant factors involved in the reduction of the data, including the value assigned for the heat of a unit amount of the standardizing reaction. As in the absolute or primary measurements, the temperature changes are made substantially the same in all experiments. The statement concerning the calibration of the thermometer following eq. 31 is also applicable here.

The value assigned to D, the heat of a unit amount of the standardizing reaction, has been previously determined in a standardizing laboratory and carries with it a standard deviation $\bar{s}'_D$ estimated according to the procedure outlined under absolute or primary measurements. Then the final "overall" standard deviation to be assigned to the experimental value of Q that is obtained from these comparative or secondary measurements is

$$\bar{s}'_Q = Q\sqrt{[\bar{s}'_{C/D}/(C/D)]^2 + [\bar{s}'_{Bg}/Bg]^2 + [\bar{s}'_D/D]^2 + [\bar{s}'_g/g]^2}, \tag{40}$$

where g and $\bar{s}'_g$ have the same significance as in eqs. 28 and 32.

If, as in the previous case, the uncertainty in the factor g is negligible in comparison with the others, then this equation may be simplified to

$$\bar{s}'_Q = Q\sqrt{[\bar{s}'_{C/D}/(C/D)]^2 + [\bar{s}'_{Bg}/Bg]^2 + [\bar{s}'_D/D]^2}, \tag{41}$$

where the first two terms under the radical arise from the two kinds of experiments performed by the investigator, and the third arises from the experiments made in the standardizing laboratory.

3. Discussion of the procedure

In connection with the foregoing procedure for evaluating the final "overall" standard deviations to be assigned to thermochemical values obtained either from absolute (primary) or comparative (secondary) measurements, the following points are to be noted:

(a) If more than one set of measurements of a given kind is made, the means and their respective standard deviations may be combined according to the procedure given in Section III, eqs. 15 ff;

(b) The number of experiments in any one set should be made sufficiently large to insure that the estimated standard deviations obtained for the magnitudes A/f, Bg, or C/D (see above) reasonably represent the behavior of the apparatus[10];

(c) Acceptable experiments include all except those in which a mistake or gross error has obviously been made, or in which an extraordinarily large deviation can be accounted for by purely physical means.

It is important to note also that the following assumptions have been made in estimating the standard deviations according to the procedure outlined here:

(a) The experiments are performed under conditions corresponding to a state of statistical control;

(b) The customary theory of probability, when applied to data in statistical control, gives in the long run the relative frequency with which intervals $\bar{x} \pm \lambda s$ (based on the observed mean value $\bar{x}$ and the consistency of the data, past or present) actually overlap the mean of a large number of observations;

[10] In the investigations carried on in the thermochemical laboratory at the National Bureau of Standards (see reference [11] for a summary of most of them), the practical optimum number of experiments per set appears to be in the neighborhood of 8 to 12, depending upon the particular substance being studied, its availability in adequate quantities of the sufficiently pure material, etc. It is, of course, presupposed that the apparatus has been brought into a state of control by previous experimentation so that the observations recorded on the substance under investigation can be considered truly random.

(c) The limiting mean μ is called the value of the quantity whose measurement is the purpose of the experiments.

4. The uncertainty interval

To each experimental value determined in the thermochemical laboratory of the National Bureau of Standards there is assigned a number representing the uncertainty interval, within which future determinations of the given experimental quantity may with reasonable certainty be expected to lie.[11] The value adopted for this uncertainty interval is twice the final "overall" standard deviation, i.e.,

$$\textit{Uncertainty interval} = 2\bar{s}'_Q, \tag{42}$$

where $\bar{s}'_Q$ is given by eq. 32 for the absolute or primary measurements, and by eq. 40 for the comparative or secondary measurements.

When two investigations yield, for a given thermochemical constant, values which differ by more than the sum of the two assigned uncertainty intervals, it is probable, but not at all certain, that a systematic error or combination of errors exists in one or both of the investigations. Conversely, when the two values are in accord within their assigned uncertainty intervals, it is probable, but not at all certain, that systematic errors are absent. When two such values differ by more than the sum of the assigned uncertainty intervals, it is desirable to reexamine the data of the experiments and ascertain whether all the necessary constant factors (see Section V-2) have been included and properly evaluated, and whether the standard deviations assigned to these constant factors have been properly estimated. Need of revision may be discovered either in the numerical values of the constant factors, or in the standard deviations assigned to them, or in both.

This assignment of uncertainty intervals to thermochemical values has, as a matter of record, been found to be of considerable practical usefulness in a number of thermochemical laboratories, and with appropriate limitations, their use is recommended to others engaged in similar work of determining thermochemical quantities.

The authors wish to acknowledge the benefit of discussion with L. W. Tilton.

VI. REFERENCES

1. Deming, W. E., and Birge, R. T. *On the statistical theory of errors.* Rev. Mod. Physics **6**: 119–161. 1934. (Revised and enlarged edition published by the Graduate School of the U. S. Department of Agriculture, Washington, 1938.)

[11] See references [3] and [9] for an extended discussion of uncertainty intervals.

2. NEYMAN, J. *Lectures and conferences on mathematical statistics.* 1938. (Graduate School of the U. S. Department of Agriculture.)
3. SHEWHART, W. A. *The economic control of quality.* 1931. (Van Nostrand, New York.)
4. SMITH, D. E. *Source book in mathematics.* 1929. (McGraw-Hill, New York.)
5. WHITTAKER and ROBINSON. *Calculus of observations.* 1924. (Blackie & Son, London.)
6. FISHER, R. A. *Statistical methods for research workers.* 1932. (Oliver & Boyd, Edinburgh.)
7. SWIETOSLAWSKI, W. *Definition of absolute and comparative measurements.* Proc. 12th Conf. Int. Union Chem., Paris, p. 87. 1936.
8. WASHBURN, E. W. *The problem of establishing the identity and purity of a hydrocarbon obtained from petroleum.* Ind. Eng. Chem. **22**: 985–988. 1930.
9. SHEWHART, W. A. *Statistical methods from the viewpoint of quality control.* 1939. (Graduate School of the U. S. Department of Agriculture.)
10. ROSSINI, F. D. *Modern thermochemistry.* Chem. Reviews **18**: 233–256. 1936.
11. ROSSINI, F. D. *Heats of formation of simple organic molecules.* Ind. Eng. Chem. **29**: 1424–1430. 1937.
12. DEMING, W. E. *Least squares.* (Graduate School of the U. S. Department of Agriculture.)

PALEONTOLOGY.—*A paleoniscid brain case.*[1] THEODORE H. EATON, JR., Union College, Schenectady, N. Y. (Communicated by C. LEWIS GAZIN.)

Present sources of information on the paleoniscid neurocranium are principally three: Stensiö (1921, *Birgeria mougeoti* from the Spitzbergen Triassic), Watson (1925, *"Paleoniscid A"* and *"Paleoniscid B"* from the Kansas Carboniferous), and Case (1937, a paleoniscid similar to Watson's *"A,"* from the same horizon, Upper Pennsylvanian, Kansas City, Mo.). A specimen of the latter type, very kindly lent to me by Dr. Case, is the material for the present study. It is no. 18565, Museum of Paleontology, University of Michigan.

Important characteristics of the paleoniscid neurocranium, as shown in the papers cited, are these:

1. The brain case is tropibasic, an actinopterygian feature; that is, the large eyes have encroached on the interorbital wall until it disappeared, and the brain retreated accordingly to a position behind the eyes and between the auditory capsules.

2. Also associated with tropibasy is a myodome, a recess for the cranial attachment of the rectus eye muscles; this has eaten still farther into the brain case, beneath the anterior part of the auditory region on each side.

3. The endocranial ossifications are few but extensive, particularly a single anterior "sphenoid," paired "autosphenotics" forming the postorbital processes, and "prootico-occipitals" enclosing the auditory capsules (Stensiö, 1921). Watson (1925) found a narrow zone of chondrification separating the prootic from the occipital parts. This was confirmed by Case and is readily visible in the present specimen.

[1] Received April 27, 1939.

A distinction between the parasphenoid and basioccipital may be seen ventrally, but in general it is extremely difficult to recognize separate centers of ossification.

4. An enclosed aortic canal occurs in Watson's and Case's specimens but was not observed by Stensiö, who could give little information about the occipital region of *Birgeria*.

5. The spiracle is enclosed in a short canal.

6. Two large median fontanelles occur on the dorsal side, one anterior, the other posterior to the synotic tectum.

Stensiö made certain comparisons with other Actinopteri and with Crossopterygii; Watson carried the comparisons much farther, having better material; Case described a nearly perfect case of the brain and labyrinth, but regarding externals he simply noted a close agreement with Watson. My study adds several details of the soft anatomy, by restoration, and certain interpretations not previously made, while the publication of Romer's (1937) study of the brain case of *Megalichthys* improves greatly the possible comparisons with crossopterygians.

Specific features.—Since the genus and species can not be determined from the brain case alone, the more significant differences between brain case 18565 and that of Watson's paleoniscid A, the nearest to it, may be summarized here (see figures):

1. Aortic canal: tapers caudad in 18565, expands caudad in "A."

2. Second efferent branchial artery: shows no sign of a groove in 18565 but has a definite groove outside the foramen in "A."

3. Groove for lateral radix of dorsal aorta: runs more anteriorly than laterally in 18565, but much more laterally in "A."

4. Spiracular groove: continues far ventrad, nearly to the basipterygoid process, in 18565, but Watson shows none at all on the ventral side of "A."

5. Basipterygoid process: close against ascending process of parasphenoid in 18565, but separated from the ascending process by at least the latter's width in Watson's "A."

There are other less significant differences of proportion of parts, but these show that the specimens are at least specifically distinct. The specimen described here is remarkably good, but not perfect, and it will be impossible to discuss adequately the orbit, myodome, snout, or anterior part of the roof of the cranium. Other parts show well and with little apparent distortion. For the brain and labyrinth see Case (1937).

Spiracular region.—A ventral or dorsal view (Figs. 1, 2) shows a

large blunt projection on the side of the postorbital region. This is formed, ventrally, by the ascending process of the parasphenoid and is penetrated dorsoventrally by the spiracular canal. The jugular canal passes through more internally, in a nearly longitudinal direction, and a troughlike facet marks the position of the hyomandibular articulation, externally and behind the spiracular canal (Fig. 3). The spiracular canal opens dorsally into a fossa, which spreads caudad to a peculiar deep pit located just above the horizontal semicircular canal. This pit in the present specimen (18565) closely matches the position of the external opening of the spiracle in such a form as *Cheirolepis* (Devonian), and it may be, therefore, that the dorsal course of the spiracular duct was drawn backward. In *Amia*, which likewise has the spiracle enclosed in a canal, there is no such dorsal trough in the neurocranium, and the external opening is directly upward, behind the eye. In *Polypterus*, without an enclosed spiracular canal, there is also no such trough or more posterior pit. Yet the smooth and definite continuity of the trough in the paleoniscid makes it very difficult to imagine any other function than carrying the dorsal part of the spiracular duct.

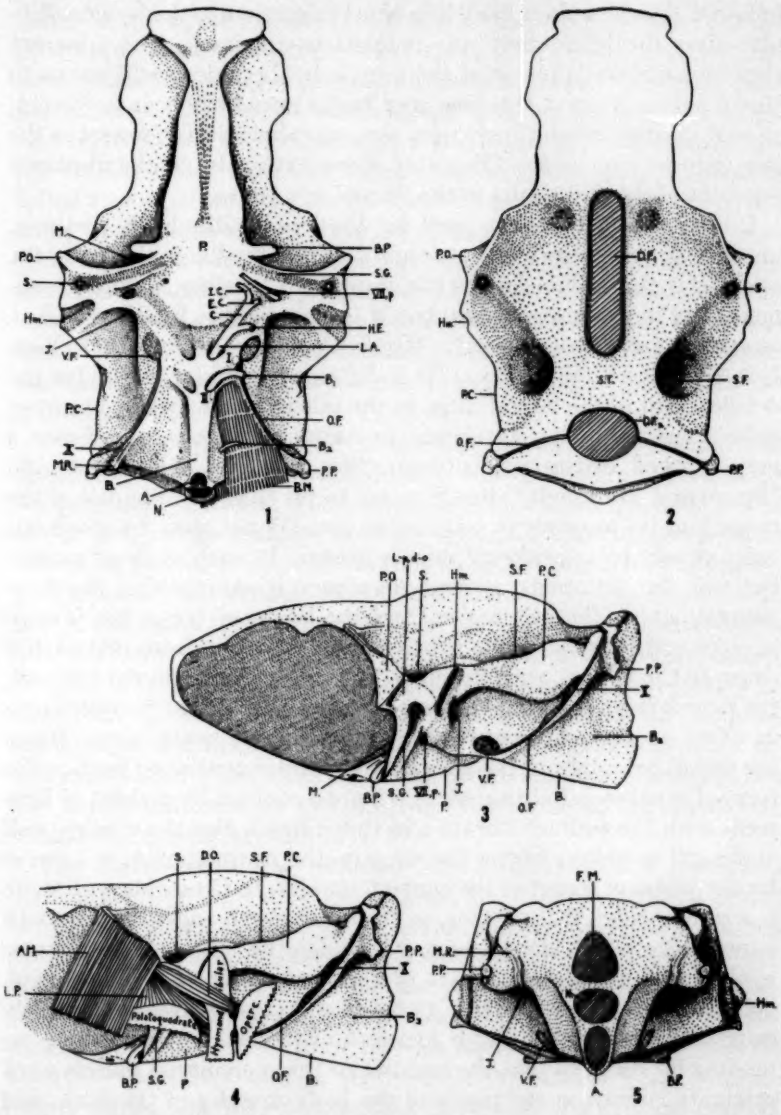
From the ventral opening of the spiracular canal a narrow but distinct groove runs down and forward, approaching the midventral line. Clearly this carried the lower part of the spiracular duct to the roof of the pharynx.

The anterior face of the postorbital process forms a triangle facing outward, and the roofing bones must have attached to it along its dorsal rim. Judging from *Amia* (Allis, 1897) and *Polypterus* (Allis, 1922) the external division of the adductor mandibulae, or a part of that division, originated on this triangular face. The internal divisions would, of course, have originated on the palatoquadrate. Then the distinct excavation behind this triangle, and lateral to the spiracular canal, housed the origin of the levator palatoquadrati and the smaller, more posterior dilator operculi. The levator palatoquadrati descends fanlike in *Amia* and *Polypterus* to insert on the dorsal edge of the palatoquadrate and anterior face of the hyomandibular. In all probability this arrangement had been established in the paleoniscids, since the amioids and Polypterini are known to represent divergent lines of descent from them. All these muscles are innervated by the trigeminus and are therefore properly jaw muscles. But the dilator operculi reaches back (in *Amia*, *Polypterus*, and other Actinopteri) across the head of the hyomandibular and inserts, usually by a tendon, on the inner face of the operculum. In most of

these fishes the distance to reach is considerable, and the muscle is nearly horizontal. In the paleoniscids, however, consideration of the parts involved suggests a fairly short muscle, and there is no evidence of a distinction, at the origin, between this and the levator palatoquadrati. (In the development of the embryo in modern Actinopteri the two arise as one, but take different insertions.) In a previous paper (Eaton, 1939) written before seeing the paleoniscid neurocranium, I suggested that the operculum of "higher" fishes, including Actinopteri, might have been derived from a mandibular type of operculum like that found in acanthodians. If so, the trigeminus innervation of the dilator operculi would be explained easily by supposing that this muscle attached to the operculum when the latter articulated with the mandibular series of bones; it would then have

ABBREVIATIONS FOR FIGURES

A.—Canal for dorsal aorta
A. M.—Adductor mandibulae
B.—Basioccipital
B. M.—Segmental body muscles
B_1, B_2—Branchial efferent arteries 1 and 2
B. P.—Basipterygoid process
C.—Common carotid artery
D. $F._{1,2}$—Dorsal fontanelles 1 and 2
D. O.—Dilator operculi
E. C.—External carotid artery
F. M.—Foramen magnum
H. E.—Hyoidean efferent artery
Hm.—Facet for hyomandibular
I. C.—Internal carotid artery
J.—Jugular canal
L. A.—Lateral dorsal aorta
L. P.—Levator palatoquadrati
L–p, d–o.—Origin of levator palatoquadrati and dilator operculi
M.—Location of myodome
M. R.—Ridge probably at edge of body muscles
N.—Notochord canal
O. F.—Otico-occipital fissure
P.—Parasphenoid
P. C.—Parotic crest
P. O.—Postorbital process
P. P.—Paroccipital process
S.—Spiracular canal
S. F.—Supraotic fossa
S. G.—Spiracular groove
S. T.—Synotic tectum
V. F.—Vestibular fontanelle
I, II—Probable locations of first branchial articulations
VII, p—Palatine branch of facial nerve
X—Vagus foramen



Figs. 1–5.—Paleoniscid brain case. 1, Ventral aspect, with certain details restored. Length 27 mm. 2, Dorsal aspect, anterior part incompletely preserved. 3, Lateral aspect. 4, Lateral aspect, with certain parts restored. 5, Posterior aspect. All figures about three times natural size.

followed the operculum back in a short migration to the hyomandibular after the hyoid cleft was reduced to a spiracle. The apparent shortness and obliqueness of the muscle in the paleoniscid seems to lend a new support to this idea, and might even have been predicted, since it means that the operculum was, morphologically, nearer to the jaw than in later types. This also shows externally in the apparent relations of the operculum to the dermal jaw bones.

Running back from the facet for the hyomandibular is a strong, uneven parotic crest, which extends as far as the fissure between the otic and occipital divisions of the cranium. This crest is more prominent than in any other fishes, but it is also distinct in Dipnoi (*Neoceratodus*) and Crossopterygii (*Megalichthys;* see Romer, 1937, Figs. 1, 2, 5). Watson (1925) says, "It is difficult to see any reason for the development of the lateral ridge on the otic region, which is, however, quite constant in its occurrence in Actinopterygians, and forms a very marked distinction between these fish and the Osteolepids, Dipnoi and Tetrapods." But it seems to me that the function of the ridge, and its presence in osteolepids and Dipnoi, may be made out quite clearly by considering muscle origins. In each of these groups, but not the tetrapods, several muscles originate behind the hyomandibular on the otic region, and the larger of these, the levator hyoidei and levator operculi (or opercularis) come from just such a ridge. In the Dipnoi, with the operculum and hyomandibular reduced, the muscle from this ridge is the constrictor hyoidei only, which acts in effect as the whole operculum. The parotic crest, then, forms the dorsal boundary of the gill chamber, and is continued back in the form of a paroccipital process or wing, to connect by a sheet of ligament with the supracleithrum and thus furnish also the median wall of the gill chamber. Above the ridge on the neurocranium is a recess for the origin of a part of the epaxial muscles. In Crossopterygii there is a similar ridge, but shorter, in the same place, and with a smooth lateral edge which doubtless provided for the origin of the levator hyoidei and the anterior part of the constrictor. The photograph published in *Time* (April 3, 1939) of a living coelacanth recently caught off the coast of South Africa shows a broad opercular flap extending far back, so that the constrictor (or opercularis) muscle must originate largely on the fascia of the body muscles of the neck, and only a little on the skull. This condition is much like *Neoceratodus*. Above the parotic ridge (*Megalichthys*) is a supraotic fossa, as in Dipnoi, obviously for epaxial muscles. In the paleoniscid there may have been no distinction, at their origin, between the levator hyoidei,

going to the hyomandibular, and the levator operculi (the reduced homologue of the constrictor above mentioned), but both must have been present and have originated on the lateral face of the prominent parotic crest. The shiny surface here indicates a large muscle origin. In *Polypterus* the two are scarcely distinct except at their insertions, but in *Amia* they are more so, and the levator operculi apparently forms two separate muscles. In addition, more posteriorly and ventrally in the same region, there are levator muscles for the branchial arches, but these leave no apparent marks on the paleoniscid neurocranium. The only essential difference left, then, between the parotic crest of paleoniscids and that of other fishes seems to be that there was no room for any epaxial muscles to reach forward into the supraotic fossa, mentioned before as the probable dorsal opening for the spiracular duct.

Ventral aspect.—The ventral surfaces of the parasphenoid and basioccipital together have the shape of a cross, the arms of which are the ascending processes of the parasphenoid, each marked by a shallow groove for the ventral end of the spiracular duct. Anterior to the ascending process is the orbit and the short but prominent basipterygoid process, while behind, on each side, is a deep jugular fossa. At the side of the basioccipital occurs a small oval pit, the vestibular fontanelle (Watson) from which the otico-occipital fissure runs posterodorsally (Figs. 1, 3). This fontanelle and fissure mark, evidently, the embryonic distinction between the otic region and the occipital segments added to the cranium behind it. Except during early development such a gap does not occur in the cranium of other fishes. The fissure continues up to the second fontanelle on the dorsal side, behind the synotic tectum (Fig. 2).

The dorsal aorta was enclosed in a canal within a prominent median ridge of the basioccipital (Figs. 1, 5). At the anterior end of the canal there are two pairs of foramina, the first being for the lateral radices of the aorta. A groove leads anterolaterally from each of this first pair of foramina, indicating the course of the arteries. Just in front of the vestibular fontanelle a slight smoothing of the surface suggests the location of the hyoidean efferent; anterior to this the artery would be, of course, the common carotid. A small foramen somewhat mediad from the arterial groove is for the internal carotid; the external carotid would not have entered the cranium, and its further course can not be seen. Returning to the aortic canal, the second pair of foramina would, then, have been for the first branchial efferents. Halfway between these and the posterior end of the aortic

canal a very small pair of foramina emerge from the canal, which could only have carried the second branchial efferents, but they seem disproportionally reduced. *Polypterus* is the only living actinopteran that is known to have an aortic canal enclosed in the neurocranium. It differs from the paleoniscid in that only the hyoidean and first branchial efferent arteries enter the canal, the others being behind the limits of the brain case. *Megalichthys* shows a pair of divergent aortic grooves in the base of the cranium, but they are not enclosed, and their union to form the dorsal aorta was more posterior than the end of the cranium. Otherwise, to my present knowledge, Stensiö's (1927) cephalaspid cyclostomes are the only vertebrates in which the aorta was enclosed in the neurocranium.

A distinct oval foramen at the base of each parasphenoid wing, behind the spiracular groove, and lateral to the internal carotid foramen, is evidently for the palatine branch of the seventh nerve. Watson shows a foramen on the side of the otic region, posterodorsal to the vestibular fontanelle and just below the parotic crest, for the ninth nerve, but it is not possible to see this in the present specimen. The surface there is partly disintegrated. The tenth (vagus) nerve evidently emerged from an expanded part of the otico-occipital fissure, also just below the parotic crest; the opening is double.

In *Amia* the first two branchial arches attach to the cranium at points just in front of the proximal ends of their respective efferent arteries. The first one, only, articulates with the cranium in *Polypterus*. The articulating end of the first branchial in each case is forked. The levator muscles for the arches originate laterodorsally to the gill chamber near the vagus foramen. In the paleoniscid it seems probable that the first two arches connected with the basioccipital close to the two pairs of anterior openings of the aortic canal, as indicated in Fig. 1. The location for the first one is indistinguishable, but that for the second seems to show as a faint ligament scar just behind the foramen for efferent artery 1. Presumably the levator muscles originated on the parotic crest just anterior to the vagus foramen and the otico-occipital fissure, thus being in line with the serially homologous levator hyoidei plus levator operculi.

Occipital region.—At the lateral extremity of the occiput occurs, on each side, a prominent knob projecting posteriorly, which has not been described before. This shows most clearly in the posterior view (Fig. 5). Comparison with other Actinopteri identifies it as a paroccipital process, from which a ligament extended to the post-

temporal. This comparison also clears up the interpretation of the paroccipital area in other groups of fishes. In Actinopteri, Dipnoi, and Crossopterygii the shoulder girdle is connected with the skull. In Actinopteri the connection is not only by a dermal articulation of the posttemporal with (usually) the epiotic, but also by a ligament running from a ventral process of the posttemporal to a process on the pterotic (teleosts) or opisthotic (more primitive types). The latter process is the one described here as paroccipital. The true opisthotic bone, homologous with that in tetrapods, is a cartilage bone, but apparently in the higher Actinopteri it tends to be crowded out by the dermal pterotic, sometimes erroneously called opisthotic. The process in question, with its ligament (which may ossify) remains in place regardless of which bone may form it.

In Dipnoi (*Neoceratodus*) the parotic crest previously described continues back to connect by a short broad ligament with the supracleithrum, forming the median wall of the gill chamber. In this case the end of the crest from the neurocranium is obviously the paroccipital process, functionally the same as in Actinopteri. It has the same relation to the branchial chamber and to the occipital face of the cranium, besides attaching to the shoulder girdle.

In *Megalichthys* (Romer, 1937, p. 12 and Fig. 5) there occurs a small knob whose morphological relations to the rest of the cranium are much the same as in the paleoniscid; that is, it faces posteriorly in line with the parotic crest, below the supraotic fossa and lateral to the area of greatest muscle attachment. This Romer termed provisionally the paroccipital process, remarking that it was "obviously an important point of attachment." I do not hesitate to identify it with the paroccipital process in the paleoniscid, which carried a ligament to the shoulder girdle, and I infer that it did likewise in *Megalichthys*. The process would be rather out of the way for a branchial arch articulation, as only the first one or two arches probably reached the skull and they would have been fairly near the hyomandibular facets and far more ventral than this process.

In tetrapods the arrangement of parts changes markedly on account of the loss of a shoulder girdle connection with the skull and because the loss of the operculum and the reduction of the hyomandibular eliminates the levator operculi and modifies the levator hyoidei; the latter changes its insertion to the mandible and becomes the depressor mandibulae of amphibians, reptiles, and birds. There is still a parotic crest, essentially as in fishes, above the jugular vein. Any process developed on this crest or near it would be, probably, a new

one; such, for example, as the process to which the dorsal arm of the stapes articulates in some reptiles. The term "parotic process" would perhaps be more satisfactory here. It is sometimes, but not always, used.

The area of attachment of muscles to the occipital face of the brain case seems to be as follows: from the dorsal rim down to the sides and lower corners of the foramen magnum and, ventrally, reaching forward nearly as far as the second pair of aortic canal foramina (first branchial efferent arteries); laterally the muscle area reaches to a curious low ridge near the paroccipital process. This ridge probably served for attachment of the external fascia of the epaxial muscles. The area as a whole, including the ventral extension forward, corresponds very closely with that in *Amia*. The posterior end of the parotic crest forms a knob which may have provided the most dorsolateral attachment for the muscle.

Finally, turning to the dorsal aspect of the neurocranium, it is worth noting that the two median fontanelles are practically the same as in the chondrocranium of *Acipenser*, but narrower. *Polypterus* has the anterior one divided by an "epiphysial bar," and lacks the posterior one.

SUMMARY

1. The more important ways in which the paleoniscid brain case shows relationship to that of other Actinopteri are these:

A. *General.* The skull is tropibasic and from the ventral side the parasphenoid and basioccipital appear as a cross. There is a pair of median dorsal fontanelles, one or both of which usually appear in the chondrocranium of modern Actinopteri. The muscles of the palatoquadrate, hyomandibular, and operculum appear to have been closely similar to those of *Amia* and *Polypterus*. A strong paroccipital process is present, indicating a ligament to the posttemporal as in most modern forms.

B. Resemblance to *Polypterus*. The aorta occupied a closed canal in the basioccipital; this canal, however, formed a projecting median ridge, absent in *Polypterus*. In connection with *Polypterus* De Beer (1937) shows that its lack of a myodome is evidently secondary, and is correlated with retention of the embryonic hypophysial foramen through the parasphenoid. Such a foramen is lacking in the paleoniscid, and the myodome, as with most other Actinopteri, is well developed.

C. Resemblance to *Amia*. The spiracle is enclosed in a short

canal. In general the features of the brain case are sufficiently near to those of *Amia* to make detailed comparison useful, but this seems to be the only exclusive agreement between *Amia* and the paleoniscid.

D. Resemblance to *Acipenser*. The two dorsal fontanelles of the paleoniscid are far more like those of *Acipenser* than of any others.

E. Special peculiarities. There is a deep supraotic pit connected by a trough with the spiracular canal, and the only interpretation the writer can make is that this carried the dorsal end of the spiracular duct. On the ventral side there is a groove for the spiracle, going toward the middle line. No supraotic fossa for the epaxial muscles is present. The otic and occipital portions are separated by a narrow fissure occupied by cartilage. The parotic crest, for the levator hyoidei and levator operculi, is much more conspicuous than in other Actinopteri. The ridge containing the aortic canal, in the basioccipital, projects down like a keel.

2. Points of particular interest in comparison with Dipnoi and Crossopterygii are these: The parotic crest is shown to be present in the latter two classes also, and to have the same morphological relations to the otic region, gill chamber, and the muscles of the hyomandibular and operculum. The paroccipital process of the paleoniscid is identified not only with that of the Actinopteri but with a similar process in Dipnoi and Crossopterygii, and the relations of the skull to the shoulder girdle are shown to be similar. The greatest contrast of the paleoniscid with these two classes is in its tropibasic skull, but tropibasy was achieved independently in the coelacanths.

LITERATURE CITED

ALLIS, E. P. *The cranial muscles and cranial and first spinal nerves in* Amia calva. Journ. Morph. 12(3): 487–808, pls. 20–38. 1897.

——— *The cranial anatomy of* Polypterus, *with special reference to* Polypterus bichir. Journ. Anat. 56(3, 4): 189–294, pls. 3–24. 1922.

CASE, E. C. *The brain and skull of a paleoniscid fish from the Pennsylvanian of western Missouri.* Proc. Amer. Phil. Soc. 78(1): 1–10, 2 pl. 1937.

DE BEER, G. R. *Development of the vertebrate skull.* Oxford. 1937.

EATON, T. H., JR. *Suggestions on the evolution of the operculum of fishes.* Copeia, 1939(1): 42–46. 1939.

ROMER, A. S. *The braincase of the Carboniferous crossopterygian* Megalichthys nitidus. Bull. Mus. Comp. Zool. 82(1): 1–73, 16 figs. 1937.

STENSIÖ, E. A. *Triassic fishes from Spitzbergen.* Pp. i–xxviii, 1–307, 35 pls., 90 figs. Vienna. 1921.

——— *The Downtonian and Devonian vertebrates of Spitzbergen. Part I. Cephalaspidae.* Skrifter om Svalbard og Nordishavet. Det. Norske Videnskaps-Akademi i Oslo. No. 12, 391 pp., 1 map, 103 figs., 112 pls. 1927.

WATSON, D. M. S. *The structure of certain paleoniscids and the relationships of that group with other bony fishes.* Proc. Zool. Soc. London, 1925, pp. 815–870, 2 pls., 30 figs. 1925.

ENTOMOLOGY.—*Notes and descriptions of United States scarab beetles.*[1] LAWRENCE W. SAYLOR, U. S. Bureau of Biological Survey. (Communicated by EDWARD A. CHAPIN.)

Since it is probable that within the near future another supplement will be added to Leng's catalogue of the Coleoptera, I wish to bring to attention certain synonymy as well as additions to knowledge of southwestern scarabs.

Phyllophaga (Phyllophaga) rossi, n. sp. Fig. 6

Male.—Oblong-oval, wider behind; above rufocastaneous and pilose; head and thorax shining, elytra slightly to moderately densely pruinose. Head with the clypeus transverse and flat, its apex truncate and angles rounded; disk with coarse, regularly placed punctures, not pilose; punctures of the front quite large, dense, contiguous, and scabrose, with long erect hair. Antenna 9-segmented, club testaceous and subequal to funicle in length. Thoracic disk with scattered and sparse, umbilicate punctures, each with a very long erect hair; these punctures on the apical half of the disk are nearly twice as large as those on the basal half; lateral margin coarsely crenate and with very long cilia; basal margin obsolete; front thoracic angles acute, hind angles obtusely angulate. Elytra with very fine and moderately dense punctures, without traces of striae except for the weakly indicated sutural striae; punctures with very small, procumbent hairs; there are longer and erect hairs scattered along the scutellar area and at the apex, the lateral margins also have a dense fringe of cilia. Pygidium convex, polished, with moderately dense, coarse, umbilicate punctures, at the sides and along the base the punctures are smaller and contiguous; disk with a moderately dense covering of small semierect hairs and also numerous very long erect hairs. Abdomen flattened, faintly concave at center and with sparse, fine punctures; fifth sternite somewhat rugose at middle and with much coarser punctures at sides, apical half varying from flat to slightly longitudinally sulcate; sixth sternite short, transversely impressed, basal margin slightly carinate, center of disk with a short longitudinal sulcus. All claws with a sharp median tooth, base hardly dilated. Hind tibial spurs free; first tarsal segment shorter than the second. Except for submarginal rows of ciliate punctures, the entire surface of the posterior femur is highly polished and impunctate. Length 12–13.5 mm. Width 6–7 mm.

The *holotype* and *paratypes* are from Patagonia, Ariz., and were collected in July 1937 by E. S. Ross. I take pleasure in naming the species after Mr. Ross, of the University of California, to whom I am indebted for many favors and specimens in the past. Two additional paratypes taken at the same time and place by M. A. Cazier also are in my collection. The type will be placed in the United States National Museum on permanent loan, and one paratype will be deposited in the collection of Dr. M. A. Sanderson, of Fayetteville, Ark.

This species runs to Group XV of Horn's tables, but it is not at all close to any of the included species, or to any other known from the United States. Its closest relative appears to be the Mexican *P. porodera* Bates, known from Guanajuato and Peras, but *P. rossi* differs from that species in many details among them the nonelevated and nonsinuate clypeal apex, the 9-segmented antennae, and the abdominal characters.

[1] Received April 25, 1939.

Phyllophaga submucida LeConte

Phyllophaga submucida LeConte, Journ. Acad. Nat. Sci. Philadelphia **3**: 260. 1856.

I have three specimens of this species from Rancho La Golondrina, Rio Sabinas, Coahuila, Mexico, collected June 2, 1938, by Rollin H. Baker of College Station, Tex., and very kindly presented to me by him. Not previously recorded outside of the United States.

Phyllophaga torta LeConte

Phyllophaga torta LeConte, Journ. Acad. Nat. Sci. Philadelphia **3**: 239. 1856.
Lachnosterna dampfi Arrow, Ann. Mag. Nat. Hist., **11**: 148. 1937. (New synonymy.)

G. J. Arrow, of the British Museum, has kindly compared Mexican and Texan examples of this species with the types of *P. dampfi* and reports that the two are the same. Thus the known range of *P. torta* is extended a good distance into Mexico, where it has not previously been recorded.

Phyllophaga ignava Horn

Phyllophaga ignava Horn, Trans. Amer. Ent. Soc. **15**: 280. 1887.

I have a specimen of this species from Rancho La Golondrina, Rio Sabinas, Coahuila, Mexico, June 2, 1938, collected by R. H. Baker, and another from Nuevo Leon, Mexico, June. Not previously recorded from Mexico.

Phyllophaga crinita (Burmeister)

Trichestes crinita Burmeister, Hand. Ent. (2) **4**: 359. 1855.

I have a good series of this species taken at Buena Vista, Coahuila, Mexico, July 7, 1938, by R. H. Baker, and also some from Monterrey. Recorded by Bates from Mexico.

Phyllophaga vetula Horn

Phyllophaga vetula Horn, Trans. Amer. Ent. Soc. **14**: 274. 1887.
Lachnosterna longipilosa Bates, Biol. Centr. Amer. (2) **2**: 209. 1888. (New synonymy).

I have cotypes of Bates's species, and they are the same as *P. vetula*. The range of *P. vetula* is thus extended into Mexico, where the species has not been previously recorded.

Phyllophaga lenis Horn

Phyllophaga lenis Horn, Trans. Amer. Ent. Soc. **14**: 287. 1887.
Lachnosterna anodentata Bates, Biol. Centr. Amer. (2) **2**: 208, 405. 1888. (New synonymy.)

I have compared cotypes of Bates's species with *lenis* and the two are the same.

Phyllophaga fucata Horn

Phyllophaga fucata Horn, Trans. Amer. Ent. Soc. **15**: 278. 1887.
Phyllophaga linsleyi Saylor, Pomona Journ. Ent. and Zool. 1936. (New synonymy.)

Phyllophaga (Tostegoptera) lanceolata (Say)

Phyllophaga lanceolata Say, Journ. Acad. Nat. Sci. Philadelphia **3**: 242. 1824.
Phyllophaga lanceolata arizonae Von Bloeker, Bull. Southern California Acad. Sci. **35**: 4. 1936.

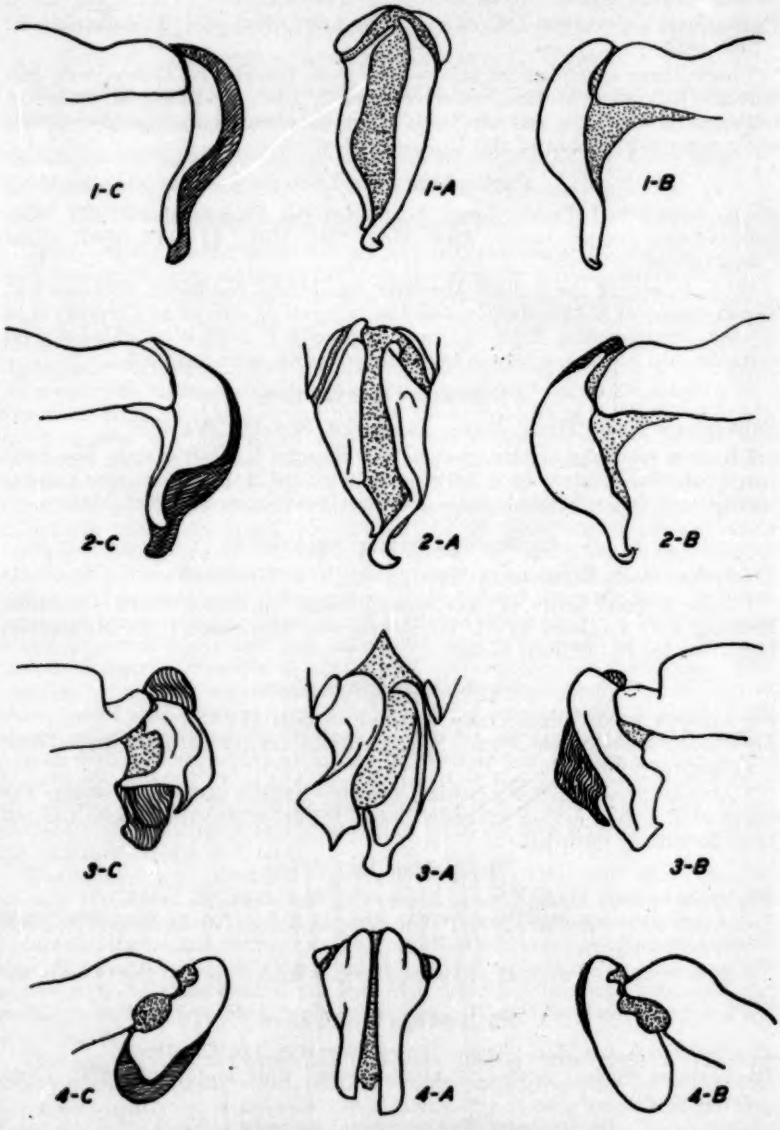


Fig. 1.—*Serica searli*, n. sp. Fig. 2.—*Serica alleni*, n. sp. Fig. 3.—*Serica mendota*, n. sp. Fig. 4.—*Serica cuyamaca*, n. sp. *A*, En face view of male genitalia; *B*, lateral view of same; *C*, same.

Phyllophaga grisiana Von Bloeker, *l. c.*, p. 5.
Phyllophaga cazieri Von Bloeker, *l. c.*, p. 6.

I have dissected paratypes of all of Von Bloeker's "species" and find that there is nothing to validate the names, even subspecifically. In Von Bloeker's description of *P. cazieri* he says: "The golden yellow scales and globosity of the female readily distinguish the species." It is well known that in species (e.g., *Thyce fieldi* Fall) ordinarily clothed with white scales the vestiture may frequently be yellow. This color variation, however, does not have subspecific or even racial significance. Variability in gibbosity of the female of any species having short or obsolete wings also must be recognized. Striking evidence of this and of the color variation may be seen in almost any large series of *P. lanceolata* even if collected at the same time and place. The male genitalia of all the forms described by Von Bloeker are exactly like those of *P. lanceolata*, as indeed his sketches show.

Phyllophaga chippewa, n. sp. Fig. 5

Male.—Elongate-oval, slightly wider behind, above polished, nearly or quite glabrous. Clypeus and front very densely, somewhat coarsely punctate, clypeus flat, apex broadly and not deeply emarginate and hardly reflexed, angles broadly rounded. Antenna 10-segmented, club a little longer than the funicle. Puncturation and shape of thorax, elytra, and pygidium and abdominal characters exactly as in *P. knochi* Horn. Fixed spur of the hind tibia three-fifths as long as the free spur. Tarsal claw with the tooth long and sharp, slightly more apical in position than in *P. knochi*. Length 18 mm. Width 9 mm.

The unique male *type* bears the data: "Schley, Minn., Chippewa National Forest, taken by L. W. Orr's collection crew on June 13, 1935 from Quaking Aspen (*Populus tremuloides*), Unit 1, Plot 3." The type was presented to the United States National Museum by R. H. Nagel and is deposited in that collection.

P. chippewa belongs in Horn's Group IX and is with difficulty separable externally from *P. knochi* Horn; the most obvious external difference between the two is the slightly more apical tarsal claw in the new species. The male genitalia are quite different, those of *chippewa* approaching closely the groups having bilaterally symmetrical claspers while *knochi* is representative of those species having strongly asymmetrical genitalia.

Serica laguna Saylor

Serica laguna Saylor, Pomona Journ. Ent. and Zool. **27**(1): 1. 1935.

This species was described from a unique male, and I have since seen two males from Idyllwild, Riverside County, Calif., collected July 4, 1929.

Serica elongatula Horn

Serica elongatula Horn, Trans. Amer. Ent. Soc. **3**: 77. 1870.

This species is one of the rarer forms of the genus; I have a goodly series collected by W. C. Reeves, at light, on May 26, 1937, at Independence, Inyo County, Calif. The fact that the species inhabits this semiarid region seldom visited by collectors may account for its rarity in collections.

Dichelonyx vicina Fall

Dichelonyx vicina Fall, Trans. Amer. Ent. Soc. **27**: 291. 1901.
Dichelonyx deserta Hopping, Can. Ent. **63**: 236. 1931. (New synonymy.)

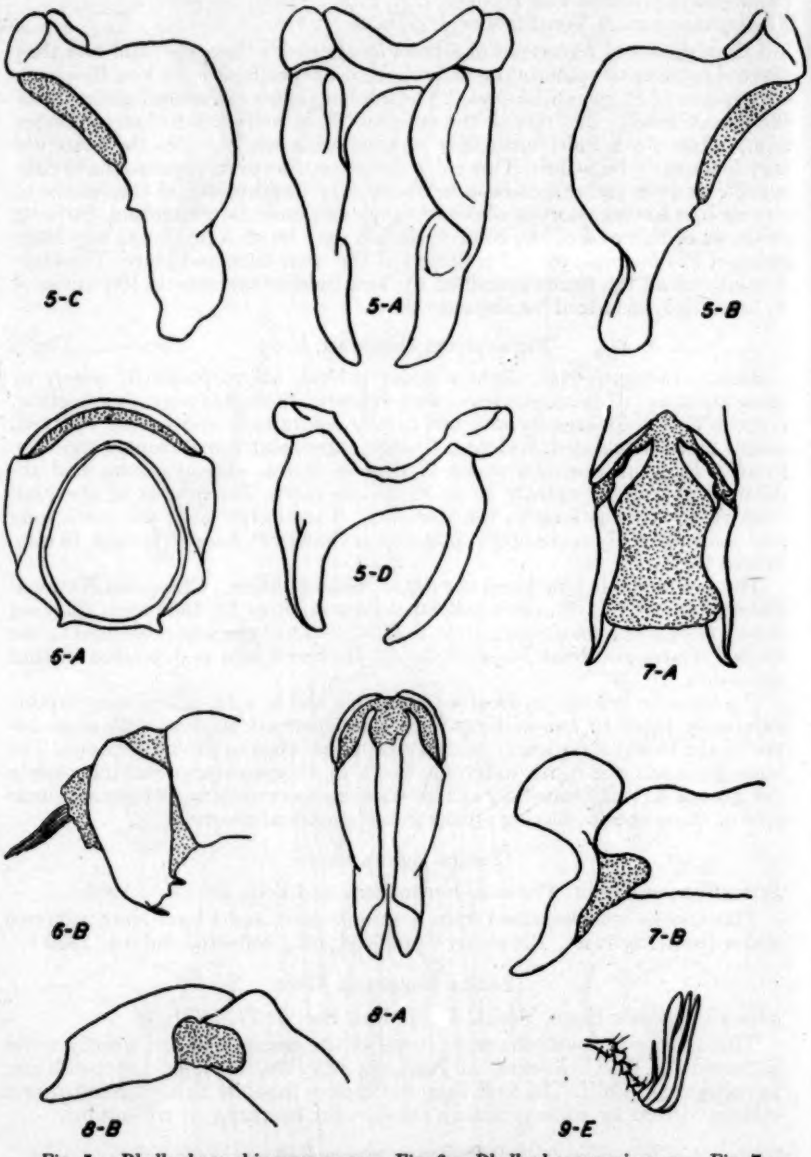


Fig. 5.—*Phyllophaga chippewa*, n. sp. Fig. 6.—*Phyllophaga rossi*, n. sp. Fig. 7.—*Serica chicoensis*, n. sp. Fig. 8.—*Serica sandiegensis*, n. sp. Fig. 9.—*Serica mendota*, n. sp. *A*, En face view of male genitalia; *B*, lateral view of same; *C*, same; *D*, dorsal view of male genitalia; *E*, male antenna.

The examination of paratypes of both of Hopping's species indicates that *D. deserta* is a straight synonym of *vicina;* the dark hairs on the head that Hopping mentions in the description are white hairs that had been covered with grease, as degreasing showed.

Dichelonyx vicina columbiana Hopping

Dichelonyx columbiana Hopping, Can. Ent. 63: 236. 1931.

D. columbiana is probably valid as a northern subspecies of *D. vicina,* since it has more coppery reflections on the elytra and thus can usually be picked from a series of the typical form.

Diplotaxis falli Saylor

Diplotaxis falli Saylor, Pan-Pacific Ent. 11: 35. 1935.

This species was described from two males from Victorville, Calif. I have recently seen specimens from Coalinga, Calif., collected May 14 by M. A. Cazier and in his collection. Through Mr. Cazier's kindness I now have the female represented in my collection.

Pachyplectrus laevis LeConte

Pachyplectrus laevis LeConte, Trans. Amer. Ent. Soc. 5: 54. 1874.

I have two specimens of this rare and little-known species, both collected in Mason Valley, San Diego, Calif., on March 27. Early spring emergence may account in part for its apparent rarity.

Serica alleni, n. sp. Fig. 2

Male.—Piceous to piceocastaneous, moderately shining, apparently glabrous above except for a few short elytral hairs. Clypeus with moderate to coarse, rugose punctures, clypeal suture hardly indicated; apex truncate, widely and shallowly emarginate, lateral margins entire. Front with coarse irregularly placed punctures, vertex impunctate. Antenna castaneous, club slightly longer than the funicle. Thorax moderately densely punctate, with a small median impunctate area. Elytra with coarse, irregularly placed punctures.

Female.—Slightly more robust, antennal club a little shorter, and abdomen strongly convex in lateral view, but otherwise similar to male. Length 8–9.5 mm. Width 5–5.5 mm.

The *holotype* male and *allotype* female are from Lake Arrowhead, Calif. (Saylor collection), collected by Paul Allen at light on June 30, 1932, and will be deposited on loan in the U. S. National Museum. Ten paratypes with the same data remain in the Saylor collection. The genitalia of *alleni* are close to *laguna* Saylor, but are distinct, and the body in the present species is more elongate and less coarsely punctate.

Serica mendota, n. sp. Figs. 3 and 9

Male.—Piceocastaneous, elytra strongly pruinose, clypeus and elytra with a few scattered hairs. Clypeus polished, slightly tumid, disk smooth at sides of apex, center with coarse and dense punctures; apex truncate, with the center margin reflexed and (viewed from directly in front of the clypeus and on a plane with the clypeal surface) raised into a moderate peak, lateral angles rounded, the sides entire. Front pruinose, with moderately dense punctures. Antenna 9-segmented, testaceous, club of 3½ segments, the fifth segment produced inwardly into a short spine and the sixth segment produced into an antennal leaf a little more than one-half as long as the seventh;

segments 7–9 inclusive slightly longer than the entire antennal stem. Thoracic and elytral puncturation very fine but obscured by the pruinosity of the surface. Abdomen in lateral view somewhat flattened. Length 8–8.5 mm. Width 4–5 mm.

The *holotype* male, also numerous *paratypes*, are from "Mendota, Calif., collected by G. T. York on April 10, 1936, and May 1, 1937" and are in the United States National Museum. Designated paratypes are also in the Saylor collection.

This species is abundantly distinct from all other described species in our fauna by the 4-segmented antennal club, shape and puncturation of the clypeus, and the male genitalia.

Serica chicoensis, n. sp. Fig. 7

Male.—Light buff-testaceous, head and thorax more brownish, surface faintly pruinose, glabrous except for a few scattered and inconspicuous short hairs on the elytra, sides of thorax, and clypeus. Clypeus tumid, densely and finely punctate, apex moderately sharply reflexed, lateral margins with a faint indication of a notch. Front finely, not densely punctate, vertex nearly impunctate. Antenna testaceous, club subequal to funicle. Thorax very finely and densely punctate, lateral margins ciliate. Elytra very sparsely and irregularly punctured between the lightly-impressed striae. Pygidium lemon-yellow, finely densely punctate, with short erect hair, and some longer intercalated hair before the apex. Length 7.5 mm. Width 4 mm.

The unique male *holotype* is in the United States National Museum and bears the data "Chico, California, collected June 24, 1937 by F. W. Turner." The genitalia are quite distinct from those of any described species of the genus.

Serica sandiegensis, n. sp. Fig. 8

Male.—Elongate, piceocastaneous above, faintly shining and with a very light pruinose bloom, glabrous except for a few scattered hairs on the elytra. Antennal club subequal to funicle. Clypeus slightly tumid at middle, disk finely and very densely punctate; apex truncate, faintly, widely and shallowly emarginate at the center, the angles narrowly rounded, lateral margins entire. Front sparsely and somewhat regularly punctate. Thorax finely and entirely punctate. Elytra moderately densely punctate between the lightly impressed striae. Pygidium with short erect hair. Abdomen slightly convex in lateral view. Claws cleft, the lower tooth much the widest of the two. Length 7.5 mm. Width 4 mm.

The *holotype* male is from "San Diego, Calif., collected by Ricksecker" and is deposited in the Casey collection at the United States National Museum; a paratype male from "San Diego, Calif. (Saylor collection)" remains in my collection. The symmetrical genitalia are not closely allied to those of any other described species in the country. Two other specimens in the Saylor collection, a pair from "San Diego, Calif., El Monte Oaks," are apparently this species though possessing slight differences which make it seem advisable to leave them without type designation. In external characters they are somewhat different, since the color is light lemon-yellow, the clypeus is more acuminate apically and the lateral edge of the clypeus is slightly though distinctly notched. The color may have been in part due to their specimens being collected in alcohol, though this is doubtful; the lateral clypeal notches are known to be somewhat variable within a species. Larger series of these El Monte Oaks specimens may well indicate a closely allied

but distinct species based on the color and clypeal differences as well as the slightly different male genitalia.

Serica searli, n. sp. Fig. 1

Male.—Piceocastaneous, robust, slightly shining, elytral apex slightly pruinose, dorsal surface apparently glabrous. Clypeus slightly tumid, disk with very dense and coarse punctures; lateral margins rounded and slightly notched near the angles; apex widely and very shallowly emarginate. Front with irregularly placed, somewhat dense punctures. Antennal club subequal to funicle. Thorax with coarse, dense punctures, those punctures of central basal area the most coarse and those areas near the hind angles the most densely punctate. Elytra with coarse, moderately dense punctures. Pygidium with dense and very coarse punctures in basal two-thirds, the punctures a little more fine apically.

Female.—Antennal club shorter than funicle, otherwise similar to male. Length 7.5–8 mm. Width 4.5–5 mm.

The *holotype* male and *allotype* female (Saylor collection) are from "Idyllwild, Riverside, County, Calif., collected April 28, 1928, by C. C. Searl" and will be deposited on loan in the United States National Museum. A male paratype from the same locality, collected on June 24, 1929, remains in the Saylor collection. *S. searli* is closest to *S. laguna* Saylor, but the male genitalia will readily separate the two.

Serica cuyamaca, n. sp. Fig. 4

Male.—Dull piceocastaneous, with slight pruinose vestiture, the dorsal surface with sparse, erect, and scattered hair. Clypeus slightly tumid, very coarsely and rugosely punctate; lateral margins entire, apex moderately reflexed widely and shallowly emarginate, the angles rounded. Front opaque, with fine and moderately dense punctures. Antenna testaceous, club slightly longer than the funicle. Thorax with very fine, dense, and regularly placed punctures. Puncturation of elytra very fine, strial intervals impunctate or with a few scattered and fine punctures. Pygidium very finely, regularly, moderately densely punctate. Abdomen convex, with moderately dense, subprocumbent hairs.

Female.—Apparently the same in all essential characters as the male. Length 7–8.5 mm. Width 4–5 mm.

The *holotype* male and *allotype* female (Saylor collection) are from "Cuyamaca, San Diego County, collected by Albert Watson on July 13, 1934" and were presented to me by the collector; these types will be deposited on loan in the collections of the United States National Museum. A paratype with the same data remains in the Saylor collection. *S. watson* Saylor is the closest described relative of *S. cuyamaca,* and the two may be most readily separated through the male genital characters.

ANTHROPOLOGY.—*A new type of artificial cranial deformation from Florida.*[1] T. DALE STEWART, U. S. National Museum.

In his *Anthropology of Florida* (1922) Hrdlička states that—

> The majority of Floridian skulls show artificial moulding. There is but one type of this: the fronto-occipital flattening; but in instances the frontal parts have been so little affected that the occipital compression alone is perceptible.
>
> The degree and frequency of the deformation differ from locality to locality, both diminishing in general, it appears, from north to south. . . . (pp. 83–85)

A review of the material available to Hrdlička in 1922 shows clearly that the majority of skulls was from the northern part of the State, especially the Gulf coast portion. Newer collections from the central and southern parts of the peninsula contain very few deformed skulls. From this fact, together with the evidence of recent archeological investigations, it seems evident that fronto-occipital cranial deformity, like many another culture trait (Stirling, 1936), represents a late culture thrust into the State from Georgia, Alabama, Mississippi, and elsewhere. Further analysis of cranial deformity in the Southeast, in connection with associated traits, will undoubtedly indicate the particular culture center from which this custom spread to Florida.

In contrast to the fronto-occipital type of deformity characteristic of the skull collections from north and northwest Florida is a new type from southern Florida with which this report is primarily concerned. This new type, for which I propose the name "obelionic,"[2] neither fits into the usual classifications of cranial deformation nor shows relationship outside of Florida. For these reasons it seems desirable to record briefly the circumstances of its discovery.

In 1929 Mr. S. H. McCrory, of the U. S. Bureau of Public Roads, informed the Division of Physical Anthropology, U. S. National Museum, of the discovery of human remains near Canal Point, Fla. A letter to Mr. Howard Sharp, editor of *The Everglades News*, elicited the information that the bones had been exposed by an excavating machine on the property of the Southern Sugar Co. Mr. C. Greenwood, the company's superintendent of cultivation, subsequently sent in a collection of the bones, including three reconstruct-

[1] Part of a paper read at the tenth annual meeting of the American Association of Physical Anthropologists, Philadelphia, April 4, 1939. Published by permission of the Secretary of the Smithsonian Institution. Received April 26, 1939.

[2] Von Bonin has used this term in connection with a similar type of deformity occurring in the Pueblo area (Southwestern United States), but in that case the term "lambdoid" has precedence and is well established in the literature.

able undeformed skulls, which Dr. Hrdlička described as "in all probability the type of the pure Calusa."[3]

In response to a request for additional material a second shipment was received, which is described as follows in Mr. Greenwood's letter of February 7, 1930:

> . . . it gives me pleasure to remit to you two packages of additional remains. [The contents of] one of these was collected from the same location as that of the previous remittance from which the Calusa type came. [The contents of] the other package was dug out of a shell mound from another part of the plantation, several miles distant from where the Calusa type was discovered.

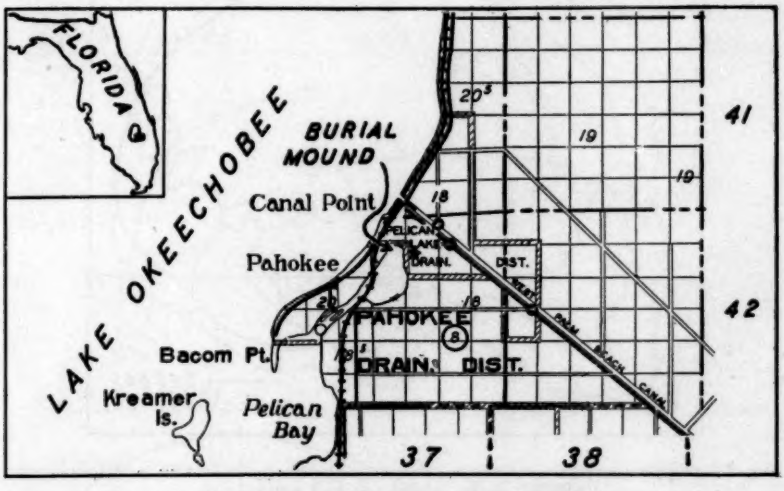


Fig. 1.—Location of shell mound containing deformed skulls.

There is nothing in the correspondence to show that Dr. Hrdlička saw this material when completely reconstructed, for at the time the second shipment was acknowledged (February 19, 1930) he said merely: "We have reconstructed in part about seven of the skulls from the first locality and they all show the same type. . . " Perhaps as a result of this statement all the material constituting the second shipment was accessioned together, with no indication that it was derived from two sites.

Recently I had occasion to examine this material and was surprised to find a number of the skulls (10) exhibiting a strange kind of de-

[3] Letter to Mr. Greenwood of January 17, 1930. The contour of one of these (345768) is shown in Fig. 2.

formity. Upon segregating the deformed specimens it was at once apparent that they were all shell encrusted, whereas the remainder of the collection under this accession (with one exception) showed evidence of burial in "muck." Then it was that Greenwood's statement regarding two sites, several miles apart, was noted in the correspondence.

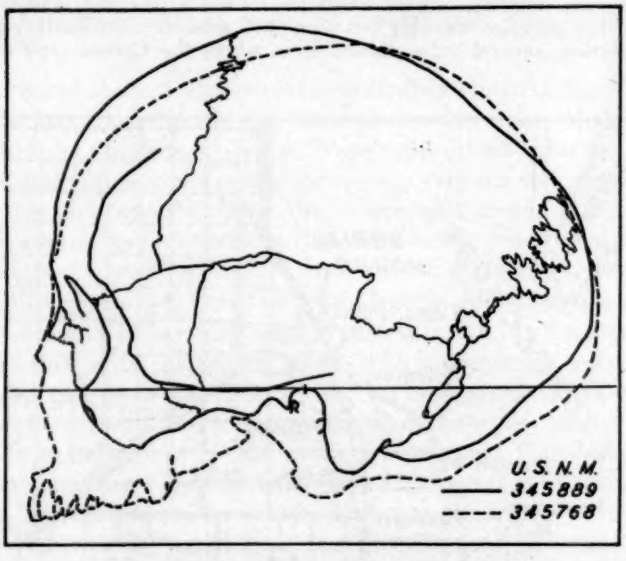


Fig. 2.—Superimposed lateral contour drawings of deformed (345889) and undeformed (345768) skulls. About one-half natural size.

I immediately wrote to Mr. Greenwood, asking for the precise location of the shell mound (second site). Although Mr. Greenwood had left the sugar company's employ in 1930, Mr. W. P. Jernigan was able to give me the desired information. A map (Fig. 1) is supplied to aid in understanding the following extract from Mr. Jernigan's letter of January 2, 1939:

> The first material . . . sent you I believe came from the southwest corner of Section 14, Township 42, South; Range 37, East. It was found about six feet below the surface when a ditch was dug on the section line. The surrounding material was the same type as all the soil in this locality, i.e., muck or peat. . . .
>
> The other specimens came from a point about one third of a mile from the northwest corner of Section 10, Township 42, South; Range 37, East, and about 200 feet from the north line of the section. The mound was of shell and marl and the bones were in the upper three or four feet. It is located on

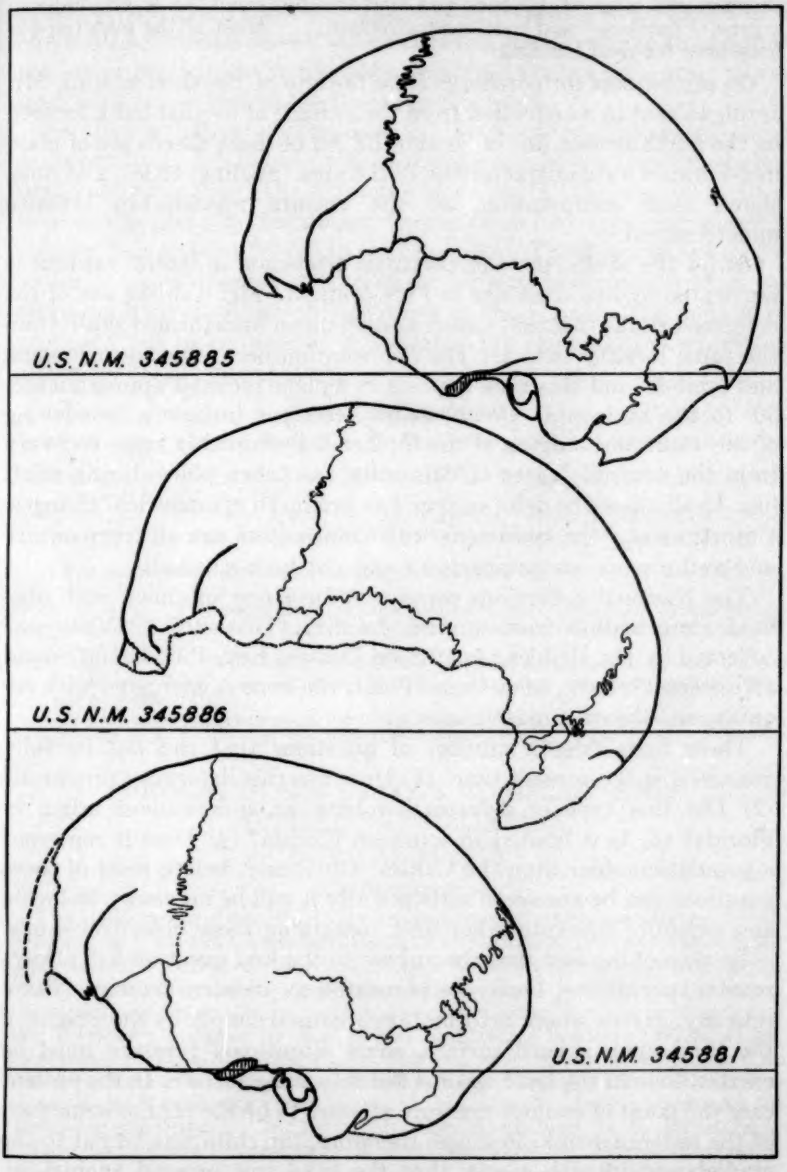


Fig. 3.—Lateral contour drawings of three skulls with obelionic deformation. About one-half natural size.

the edge of a ridge of soft rock and marl which extends for several miles in a general northeast and southwest direction. . . . Most of the material has been used for road building.

On my request for potsherds from the site of the shell mound, Mr. Jernigan sent in a collection from the surface of a canal bank located on the north section line of Section 10. All of these sherds are of plain undecorated ware characteristic of the area (Stirling, 1935), and none shows shell encrustation, so the culture relationship remains undetermined.

As for the skulls, the characteristic alteration in lateral contour is illustrated by line drawings in Figs. 2 and 3.[4] Fig. 2 shows one of the deformed skulls (345889) superimposed on an undeformed skull from the same locality (site 1). The deformation occurs between bregma and lambda, and this area appears as a plane inclined approximately 30° to the horizontal. Compensatory changes include a broadening of the vault and bulging of the forehead. Presumably some recovery from the original degree of deformity has taken place during adult life. In all cases the deformation has produced symmetrical changes. Unfortunately, the specimens with deformation are all fragmentary and anthropometric comparisons can not be instituted.

The National collections contain at least one specimen with obelionic deformation from another locality. This skull (293090) was collected by Dr. Hrdlička in 1916 on Demere Key, Pine Island Sound (West coast). Here, as at Canal Point, the bone is encrusted with coquina, and the culture is unknown.

These finds raise a number of questions that can not be fully answered at the present time: (1) How was this deformity produced? (2) Did this type of deformation have an independent origin in Florida? (3) Is it limited to southern Florida? (4) Does it represent a population older than the Calusa? Obviously, before most of these questions can be answered satisfactorily it will be necessary to locate and carefully excavate other sites containing these deformed skulls.

In view of the fact that the answer to the first question will always remain speculative, I may be permitted an opinion thereon. Theoretically, except where deformation is caused simply by the weight of the head upon a hard surface, some intentional pressure must be exerted to hold the head against the deforming surface. In the present case the point of counter pressure appears to be the chin or some part of the anterior trunk. Perhaps, therefore, the child was bound to the cradleboard in such a way that the head was pressed against an

[4] I am indebted to Mr. Georg K. Neumann for making these drawings on his stereograph (Schwarz).

inclined endpiece. This view seems more logical than that which envisions a bandage passed under the chin, for the simple reason that the latter mechanism would have deformed the jaw also, and—there is no evidence of this in the present collections.

As already indicated (footnote 2), the so-called "lambdoid" type of deformity in the Pueblo area of the Southwest is somewhat similar to the obelionic type. The difference is mainly in the degree of inclination of the plane of flattening. In the lambdoid type this plane is steeper, being about 50–60° to the horizontal. This being the case, the flattened plane does not extend so far forward as bregma, and on the other hand involves the occiput down to about inion. The method of production is unknown but is probably the same as that suggested above for the obelionic type.

LITERATURE CITED

BONIN, G. VON. *Cranial deformity in the Pueblo area.* Amer. Anthrop. **39** (4): 720–721. 1937.

GREENWOOD, C. Correspondence filed under U. S. National Museum accession numbers 108647 and 109112.

HRDLIČKA, A. *Trip to Fort Myers, west coast of Florida.* Explorations and Field-Work of the Smithsonian Institution in 1916. Smithsonian Misc. Coll. **66** (17): 28–29. 1917.

—— *The anthropology of Florida.* Publ. Florida State Hist. Soc., No. 1. 1922.

JERNIGAN, W. P. (See GREENWOOD).

STEWART, T. D. *Two new types of cranial deformity in the Southeast: (a) Fronto-parieto-occipital, (b) obelionic.* Amer. Journ. Phys. Anthrop. **25**, Suppl. to No. 1, Abs. 5 and 6. 1939.

STIRLING, M. W. *Smithsonian archeological projects conducted under the Federal Emergency Relief Administration, 1933–34.* Ann. Rep. Smithsonian Inst. 1934, pp. 371–400. 1935.

—— *Florida cultural affiliations in relation to adjacent areas.* Essays in anthropology present to A. L. Kroeber, pp. 351–357. Berkeley, Calif. 1936.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

CHEMICAL SOCIETY

506TH MEETING

The 506th meeting was held in the auditorium of the Cosmos Club on Thursday, January 12, 1939, President KRACEK in the chair. This meeting was the 55th annual meeting of the Society and the 45th annual meeting of the Washington section of the American Chemical Society. After the reading of the minutes of the preceding meeting the annual reports of the Secretary and the Treasurer, followed by that of the Auditing Committee (W. H. Ross, chairman, P. H. GROGGINS, C. E. WHITE), were read and accepted. The following committees were appointed to serve during 1939: Communications: S. B. HENDRICKS (chairman), M. M. HARING (deputy chairman for divisional meetings), L. W. BUTZ, MICHAEL FLEISCHER, G. E. HILBERT, J. I. HOFFMAN, HANS LINEWEAVER, R. S. MCBRIDE, S. N. WRENN. Entertainment: S. T. SCHICKTANZ (chairman), M. A. BRADSHAW, S. BRUNAUER, W. L. HALL, E. L. JACKSON, FLORENCE B. KING, W. B. KUNZ, W. L. LAMAR, O. H. LOEFFLER, J. MCLAREN, C. M. SMITH, E. R. SMITH, W. J. SVIRBELY,

H. G. WISEMANN. Membership: J. J. FAHEY (chairman), E. O. HAENNI, ELIZABETH HEALY, W. B. HOLTON, H. W. HOWARD, R. J. MAWHINNEY, C. R. NAESER, R. D. REMLEY, N. K. RICHTMYER, W. G. SCHLECHT, L. A. SHINN, LOUISE STANLEY, J. B. TOMLINSON, C. E. WHITE, K. T. WILLIAMS. Budget: J. H. HIBBEN (chairman), R. M. HANN, E. R. SMITH, and NORMAN BEKKEDAHL (ex officio). Finance and Investment: RALEIGH GILCHRIST (chairman), M. X. SULLIVAN, E. G. ZIES.

The Society was addressed by the retiring President, NATHAN L. DRAKE, who spoke on *Cerin and friedelin, two pentacyclic triterpenoids*. The speaker discussed the results of a long series of researches designed to elucidate the structures of these compounds, particularly in relation to the structures of the polyterpenoids in general. The research papers are published in recent volumes of the Journal of the American Chemical Society.

507TH MEETING

The 507th meeting was held in the auditorium of the Cosmos Club on Thursday, January 26, 1939, President KRACEK presiding. This was a special meeting, addressed by F. LONDON, of the Institut Henri Poincaré, Paris, who spoke on *Supraconductivity in aromatic molecules*. The speaker discussed the nature of the chemical bond, with particular application to aromatic molecules.

508TH MEETING

The 508th meeting was held in the auditorium of the Cosmos Club on Thursday, February 9, 1939, President KRACEK in the chair. After the reading of the minutes it was announced that the Hillebrand Prize Award for 1938 was to be presented at the March meeting to RALEIGH GILCHRIST and EDWARD WICHERS for their work on a new system of analytical chemistry for the platinum metals. The Society was then addressed by Professor HELLERMAN, of the Department of Physiological Chemistry, Johns Hopkins University:

LESLIE HELLERMAN: *Some recent developments concerning the constitution and mode of action of enzymes.*—Enzyme chemistry is a crossroads—a meeting ground for several fields of chemistry and of biology, nutrition, and medicine. Enzymatic mechanisms are concerned with most of the reactions of biochemistry, and modern work is developing some surprises. The enzymes that recently have been most intensively studied are found to be protein in character. This seems to have defined sharply the proposition that enzymatic catalysis is catalysis superimposed upon the complexities of protein chemistry; it also provides a more rational basis for the control of enzyme actions in experimental work. The older speculations regarding the nature of enzymes are finding limited support in current investigations upon the enzymes and coenzymes ("pyridine and flavin nucleotides," pyrophosphorylated vitamin B_1, adenosine phosphates) concerned in biological oxidation-reductions. Modern work seems to be clarifying the role of the coenzymes; also the nature of the catalysts concerned with the action of oxygen. The several recognizable factors underlying the control of biological catalysis are well illustrated on the one hand by the process of formation from their inactive precursors of the crystallizable protein-enzymes of digestion, and on the other by the behavior of certain hydrolytic enzymes and other principles with respect to reversible chemical processes, such as oxidation-reduction and probably metal-complex formation. The nature of enzyme specificity is well illustrated by the arginine-splitting enzymes. (*Author's abstract.*)

RAYMOND M. HANN, *Secretary*

Obituaries

JACOB GOODALE LIPMAN died at New Brunswick, N. J., on April 19, 1939. He was born at Friedrichstadt, Russia, November 18, 1874, but spent his early youth on a New Jersey farm. His undergraduate studies were made at Rutgers University, where he obtained his B. S. degree in 1898. For the next two years he served the New Jersey Experiment Station as assistant chemist and then entered Cornell University for his graduate studies, receiving his Ph. D. degree in 1903. For his distinguished services to agriculture he was awarded an honorary degree of D. Sc. by Rutgers University in 1923 and an honorary Ph. D. by the Catholic University of Santiago, Chile, in 1930.

After serving his alma mater in various capacities as soil chemist and bacteriologist, he was appointed director of the New Jersey Agriculture Experiment Station in 1911 and dean of agriculture in 1915, both of which positions he occupied at the time of his death. Although charged with heavy administrative duties, Dr. LIPMAN not only remained actively engaged in research but found time to serve as editor-in-chief of *Soil Science*, a journal he founded in 1915. He was editor also of the Agricultural Series published by John Wiley & Sons and contributing editor of *Annales Agronomiques*, *Pennsylvania Farmer*, *Chronica Botanica*, and *Wissenschaftliches Archiv für Landwirtschaft*.

Dr. LIPMAN'S publications constitute a long list of technical papers on soils, soil bacteriology, and agronomy. He was a corresponding member of the Swedish Royal Academy of Agriculture, French Academy of Agriculture, and the Czechoslovakian Academy. In 1922, 1924, and 1926 he was a delegate to the International Institute of Agriculture at Rome and in 1927 was president of the International Congress of Soil Science. He held membership in the Academy and the following organizations: American Chemical Society, American Society of Agronomy, Association of Official Agricultural Chemists, American Society of Bacteriology, American Public Health Association, Association of Land Grant Colleges and Universitites, American Academy of Political Science, American Academy of Arts and Sciences, Société de Chimie Industrielle, Reale Accademia dei Georgofili di Firenze, and International Society of Soil Science.

JOSEPH GRINNELL, director of the Museum of Vertebrate Zoology and professor of zoology at the University of California in Berkeley, died at his home in Berkeley, Calif., on May 29, 1939. Dr. GRINNELL was born on February 27, 1877, at Old Fort Sill, Indian Territory, in what is now Oklahoma, where under frontier conditions he lived during childhood. He attended high school in Pasadena, Calif., and in 1897 received an A.B. degree from Throop Polytechnic Institute. This was followed by graduate work at Stanford University for which he received the degrees of A.M. in 1901 and Ph.D. in 1913. He was an instructor at Stanford from 1900 to 1902 and taught at Throop from 1903 to 1908, during the last three years as professor.

To his colleagues and students of this present day JOSEPH GRINNELL is associated always with the Museum of Vertebrate Zoology, founded at the University in Berkeley in 1908 by Miss ANNIE M. ALEXANDER and supported generously by her in the years that have followed, both in funds and in personal interest. Dr. GRINNELL was chosen director at the beginning and continued in this post with attendant professorial duties until his death. For

years he was active in the Cooper Ornithological Club and from 1906 was editor of its journal, *The Condor*. As his field for research GRINNELL chose western North America, from Alaska to Baja California, and to taxonomic and ecological studies of the vertebrates of this region he devoted his active life. While best known for his work in birds, partly perhaps because of his editorship of *The Condor*, he was an authority as well on amphibians, reptiles, and mammals of this vast region. The museum established under his charge has grown until it is today the most important research center in vertebrate zoology in the West, and for many years it has been a place for training graduate students in this subject. GRINNELL himself became the outstanding figure in the Western United States in this field, with international reputation. His published works number about 550 separate titles.

JOSEPH GRINNELL was a scholarly man of quiet tastes and sensitive nature, with which he combined firmness of mind and constant industry in the field of his interests. He cared little for honors demanding public appearance and avoided them under ordinary circumstances. He was exacting and meticulous of detail in his work, and his influence has been potent in the development of his chosen field, both through his own considerable contributions and through his training of others.

WENDELL CLAY MANSFIELD, geologist of the Geological Survey, died at his home in Washington, July 31, 1939. He was born at Charlotte Center, N. Y., June 9, 1874. He received the degrees of Bachelor of Science from Syracuse University in 1908, Master of Science from George Washington University in 1913, and Doctor of Philosophy from the same institution in 1927. He came to Washington in 1910 as a preparator of fossils in the Geological Survey, by which organization he was employed continuously until his death. Doctor MANSFIELD, whose chief field of work was in paleontology, was an authority on the late Tertiary Mollusca of the Southeastern States, particularly of Virginia, the Carolinas, and Florida. He contributed many articles about fossils to this and other journals, and was the author of two professional papers of the Federal Geological Survey and of four bulletins of the Florida Geological Survey. Doctor MANSFIELD was a member of the Academy, the Paleontological Society, the Geological Society of America, and of the Geological, Biological, and Paleontological Societies of Washington.